ADA

SINGLE COMMON POWERTRAIN LUBRICANT (SCPL) DEVELOPMENT (PART 2)

INTERIM REPORT
TFLRF No. 442

by

Adam C. Brandt
Edwin A. Frame
Gregory A. Hansen
Robert W. Warden

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for

Allen S. Comfort

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD17-Task 3)

UNCLASSIFIED: Distribution Statement A. Approved for public release

April 2014

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14. ABSTRACT

The U.S. Army has a desire to consolidate multiple MIL specification fluids into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems, and must be designed to operate in ambients ranging from low temperature arctic, to high temperature desert type conditions. The U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI) has aided TARDEC in the initial development of the SCPL. This report covers the testing of two revised candidates identified in TFLRF Report No. 418. Testing included high temperate endurance in the General Engine Products 6.5L(T) diesel engine to assess engine protection and oil performance at elevated temperatures, 2-cycle diesel engine compatibility using the Detroit Diesel 6V53T, multiple industry standardized transmission tests (Allison C4, Caterpillar TO-4, John Deere JDQ) to assess frictional performance and driveline durability, and quantification of fuel consumption improvement over standard military oils through viscosity reduction in the SCPL.

15. SUBJECT TERMS

Single Common Powertrain Lubricant (SCPL), General Engine Products (GEP) 6.5L(T), Detroit Diesel Corporation (DDC) 6V53T, High Temperature Oil Endurance, MIL-PRF-46167, MIL-PRF-2104, Total Acid Number (TAN), Total Base Number (TBN), Wear Metals, Oxidation, Fuel Economy, Pumping Losses, Transmission, Caterpillar TO-4, Allison C4, John Deere JDQ-96

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EXECUTIVE SUMMARY

The U.S. Army has a desire to consolidate multiple lubricant specifications into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems where MIL-PRF-2104 is currently used. The SCPL must be designed to operate in ambients ranging from low temperature arctic, to high temperature desert type conditions, representative of the wide range of potential military operating conditions.

This report is the second in a series covering the SCPL development, and focuses on the refinement of two initial SCPL candidates identified during research reported under TFLRF Interim Report 418, Single Common Powertrain Lubricant (SCPL) Development (Part 1). All SCPL testing reported was completed at the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF), located at Southwest Research Institute (SwRI) in San Antonio, Texas. Performance investigations reported here of the revised SCPL candidates included: chemical and physical analysis, high temperature endurance testing in the General Engine Products (GEP) 6.5L(T) engine, 2-cycle diesel engine compatibility using the Detroit Diesel Corporation (DDC) 6V53T, American Society for Testing and Materials (ASTM) D5966 roller follower wear protection, frictional analysis in industry standardized transmission tests, and the quantification of fuel consumption improvement through lowered viscosities.

Two initial SCPL candidates were identified in TFLRF Interim Report 418 to receive further development and testing for the U.S. Army SCPL program. Results from initial testing was shared with industry suppliers, and specific goals were outlined for their improvement. The two initial SCPL candidates were then reformulated by each respective supplier and resubmitted as revised candidates for continued testing.

Consistent with the initial testing, the General Engine Products (GEP) 6.5L(T) engine, from the High Mobility Multipurpose Wheeled Vehicle (HMMWV), was used to complete high temperature oil endurance evaluations on each revised candidate. This allowed for comparisons between revised and initial candidates, as well as performance comparisons to current

commercial products and current MIL specification products tested and reported in IR418. End of test used oil analysis for each of these tests can be seen below in Table ES1 (Note – Full data for 2104G, 2104H, CJ-4, LO253071, and LO251746 oils were reported in IR418). Both candidates improved their performance in the GEP 6.5L(T) test from their respective initial evaluations. Revised candidate LO271510 improved from 168 hours to 196 hours, still falling slightly short of the 210 hour target. Revised candidate LO268869 improved from 126 hours to the targeted 210 hours, while still maintaining favorable oil condition and low accumulation rates of critical wear metals.

Table ES1. All Tests, End of Test Used Oil Analysis

Property	ASTM Test	MIL SPEC & Commercial			SCPL Candidates			
Lubricant		2104G	2104H	CJ-4	LO253071 *Initial*	LO268869 *Revised*	LO251746 *Initial*	LO271510 *Revised*
Hours		84	154	210	126	210	168	196
Density	D4052	0.9161	0.9276	0.920	0.896	0.8874	0.8859	0.894
Viscosity @ 100°C (cSt)	D445	17.58	25.47	25.59	12.17	13.64	11.96	15.63
Total Base Number (mg KOH/g)	D4739	0.74	1.17	0.82	2.61	4.37	3.84	4.55
Total Acid Number (mg KOH/g)	D664	12.87	17.1	11.06	10.86	7.33	9.19	9.67
Oxidation (Abs./cm)	E168 FTNG	171.63	217.99	117.53	136.69	68.76	99.08	111.73
Nitration (Abs./cm)	E168 FTNG	36.6	33.76	39.21	80.5	25.97	52.77	51.99
Soot	Soot	1.982	2.864	2.695	2.214	2.082	2.597	2.568
Wear Metals (ppm)	D5185							
Al		5	5	5.0	11	11	6	5
Sb		<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1
B		5	4	40.0	4	3	55	22
Ca		3620	3056	3522.0	4629	5393	1183	1469
Cr		6	6	6.0	6	10	7	6
Cu		234	345	65.0	311	47	48	61
Fe		264	468	355.0	476	447	541	452
Pb		332	693	378.0	564	92	152	232
Mg		13	380	30.0	17	21	1669	1995
Mn		5	6	6.0	6	7	7	6
Mo		22	21	24.0	28	32	124	132
Ni		6	6	6.0	8	8	9	9
P		1089	1302	1334.0	1366	1607	1318	1476
Si		51	38	46.0	56	46	53	56
Ag		<1	<1	<1	<1	<1	<1	<1
Na		8	<5	8.0	22	10	12	9
Sn		17	24	17.0	20	18	18	15
Zn		1544	1914	1775.0	2306	2747	1780	1979
K		<5	<5	13.0	8	10	<5	<5
Sr		1	<1	1.0	2	2	<1	<1
V		<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	1	<1	<1
Cd		1	<1	<1	2	<1	<1	<1

New in this round of testing was a 2-cycle diesel compatibility test with the SCPL candidates. A Detroit Diesel Corporation (DDC) 6V53T, from the M113A3 Armored Personnel Carrier (APC), was used to evaluate the two revised candidates and a MIL-PRF-2104H OE/HDO 15W-40 baseline to determine compatibility and performance in a 2-cycle diesel application. Both SCPL candidates provided comparable engine protection of the critical piston and liner interface in the 2-cycle engine when compared to the baseline MIL-PRF-2104H OE/HDO 15W-40 evaluation at normal ambient type engine operation. With respect to engine cleanliness, both revised SCPL candidates showed a reduced trend of deposit formation, reducing overall deposits and a tendency to experience a cold stuck condition on the 2^{nd} compression ring when compared to the baseline 2104H evaluation.

To determine transmission compatibility, several industry standardized transmission tests were completed on the revised SCPL candidates, including selected: Allison C4, Caterpillar TO-4, and John Deer Qualification tests. As with testing reported in IR418, the revised SCPL candidates were found to have mixed results overall, with no candidates being able to pass all tests (Note: JDQ and CAT TO-4 Seq 1222 tests are not required tests by the MIL-PRF-2104 product specification). There was some improvements from the first round of testing, and none of the oils tested showed signs of catastrophic incompatibilities. It is again expected that the revised candidates will be able to pass the various frictional evaluations with minor formulation changes.

Fuel consumption improvement evaluations were completed to quantify improvement with the use of low viscosity lubricants over traditional higher viscosity diesel engine oils. The GEP 6.5L(T) engine was used for testing due to its utilization of a fully mechanical fuel injection system which adds greater consistency to fuel consumption measurements. The 14 mode fuel consumption test cycle developed and reported in IR418 from data acquired during HMMWV field operations at Ft. Hood, Texas, was used to quantify fuel consumption changes. As expected, the revised candidate SCPL oils showed similar fuel consumption improvement results as seen from the initial candidates compared to the straight SAE 40 grade. This is attributed to the similar viscometric properties measured from the revised candidates. Overall, the fuel consumption improvement was greater than 1.5% over standard military diesel engine oils.

It is the recommendation of TFLRF staff that both revised candidates continue to be considered for the SCPL program. Focused formulation changes need to be made for both candidates to improve transmission performance without negatively impacting engine durability, oil degradation, and 2–cycle compatibility. Long term considerations for the SCPL program should include: high temperature 2–cycle diesel engine compatibility testing, high output air-cooled diesel engine compatibility, detailed investigation of ring pack wear changes due to lowered viscosities, and the conduct of SCPL field demonstrations at U.S. Army Installations at cold, moderate, and high temperature climate conditions.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period June 2011 through April 2014 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Eric Sattler (AMSRD-TAR-D/MS110) served as the TARDEC contracting officer's technical representative. Mr. Allen Comfort of TARDEC served as project technical monitor.

The authors would like to acknowledge the contribution of the TFLRF technical support staff.

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ACRONYMS AND ABBREVIATIONS

API – American Petroleum Institute

ASTM – American Society of Testing Materials

ATF – automatic transmission fluid

bhp – brake horse power

bsfc – brake specific fuel consumption

CAT - Caterpillar

CL – chem. lab

coeff – coefficient

COTR – Contracting Officer Technical Representative

cP – centipoise

CRC – Coordinating Research Council

cSt – centistokes

DDC – Detroit Diesel Corporation

EOT – end of test

FRRET – friction retention

ft – feet

GEP – General Engine Products

GM – General Motors

GOCO – Government Owned, Contractor Operated

HDO – heavy duty oil

HMMWV – High Mobility Multipurpose Wheeled Vehicle

hp – horsepower

hr – hour

JDQ – John Deere Qualification

JP8 – jet propulsion 8

lb – pound

ft-lb – pound feet

LO – lab oil

MIL – military

mils – (unit of measure) thousands of an inch

N – Newton

NA – naturally aspriated

NVH – noise, vibration, and harshness

OE – oil engine

OEA – oil engine arctic

OEM – original equipment manufacturer

ppm – parts per million

psi – pounds per square inch

psiA – pounds per square inch absolute

RPM – revolutions per minute

SAE – Society of Automotive Engineers

SCPL – Single Common Powertrain Lubricant

SwRI – Southwest Research Institute

TAN – total acid number

TARDEC – Tank Automotive Research and Development Engineering Center

TBN – total base number

TFLRF – TARDEC Fuels and Lubricants Research Facility

1.0 INTRODUCTION & BACKGROUND

The U.S. Army has a desire to consolidate multiple lubricant specifications into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems where MIL-PRF-2104 products are currently used. The SCPL must be designed to operate in ambients ranging from low temperature arctic to high temperature desert conditions, representative of the wide range of potential military operating conditions. In addition to this universal application, the SCPL must meet or exceed performance currently attained by approved MIL specification products. By achieving these goals, multiple lubricant specifications could be reduced into a single specification, or SCPL, that could be used successfully in tactical and combat vehicles in any seasonal or geographical location. The development of this lubricant has the potential to reduce the logistical burden on the military's supply chain, reduce operating costs, and improve performance beyond current approved and fielded products.

Due to the extreme application requirements and performance goals, it is desirable that the SCPL be formulated from synthetic basestocks. These synthetic basestocks typically have a higher cost when compared to traditional petroleum derived basestocks. To offset the increased price, several additional performance goals must be met, such as increased vehicle fuel efficiency, and extended drain intervals. Current research has shown that there is a potential reduction in fuel consumption through the use of low viscosity lubricating fluids [1,2]. This change in fuel consumption is attributed to the reduction in mechanical losses within the system. These mechanical losses can be related to shifts in frictional properties, pumping efficiencies, and overall bulk churning of the lubricant in mechanical applications. Although reductions in fuel consumption through viscosity changes are expected to be relatively small (1-2%), when incrementally multiplied over a large group of vehicles such as the military's combat and tactical fleet, the fuel savings can be substantial. These efficiency increases through reduced viscosities complement the SCPL’s requirement to provide extreme cold climate performance, as lower fluid viscosities must be obtained to ensure pumpability at low temperatures than typical average climate heavy duty diesel oils. Premium synthetic basestocks also typically offer an increased

resistance to oil degradation, which allows the extension of time required between drain intervals. This extension of service intervals, combined with the increased efficiency through lowered viscosity, helps counteract increased costs associated with synthetic basestocks [3].

This report is the second in a series covering the SCPL development, and focuses on the refinement of two initial SCPL candidates identified during research reported in TFLRF Interim Report 418, Single Common Powertrain Lubricant (SCPL) Development (hereinafter referred to as Part 1) [4]. All SCPL testing reported was completed at the government owned, contractor operated (GOCO) U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF), located at Southwest Research Institute (SwRI) in San Antonio, Texas. Performance investigations reported here of the revised SCPL candidates included: chemical and physical analysis, high temperature endurance testing in the General Engine Products (GEP) 6.5L(T) engine, 2-cycle diesel engine compatibility using the Detroit Diesel Corporation (DDC) 6V53T, American Society for Testing and Materials (ASTM) D5966 roller follower wear protection, frictional analysis in industry standardized transmission tests, and the quantification of fuel consumption improvement through lowered viscosities.

2.0 OBJECTIVE & APPROACH

The overall objective of this project was to evaluate two SCPL candidates that have been revised for improved performance based off of previously attained performance results from SCPL Development Part 1. This data would reinforce the previously completed feasibility study [5,6,7], preliminary development efforts (Part 1), and verify candidate advancement towards the goals of the SCPL.

2.1 ENGINE DURABILITY TESTING

Due to the low temperature properties required to meet SCPL performance guidelines, candidate SCPLs were expected to be formulated to attain lower viscometric properties than those seen in traditional heavy duty diesel engine oils. To ensure that these low viscosity lubricants provided adequate engine component protection at all operating conditions, particularly desert operation, high temperature engine oil endurance testing was completed in an effort to assess each revised candidates performance at worst case conditions. Consistent with testing completed during Part 1, the General Engine Products (GEP) 6.5L(T) diesel engine, as used in the High Mobility Multipurpose Wheeled Vehicles (HMMWV), was selected as the test bed for determining overall engine durability. The GEP 6.5L(T) engine is a 6.5L V8, turbocharged, non-intercooled, indirect injected, roller follower, cam in block engine. Fueling is controlled by a mechanical Stanadyne DB2-5079 rotary injection pump in a pump-line-nozzle configuration, and produces approximately 170hp on JP-8 fuel. The GEP 6.5L(T) engine was selected primarily because of its traditionally rapid degradation of engine oil during use (i.e., high severity), and the engine family's high density in the current military fleet (engine family includes the GEP 6.2L(NA), 6.5L(NA), and 6.5L(T) in all variants of the HMMWV). Results from revised candidate testing were used to determine performance improvement in comparison to each initial first round candidate evaluation, MIL-PRF-2104 (G and H revisions) evaluations, and the commercial 15W-40 baselines completed during Part 1.

In addition to engine durability using the GEP 6.5L(T), each revised candidate was also evaluated using the Detroit Diesel Corporation (DDC) 6V53T. The DDC 6V53T test was used to determine 2-cycle diesel compatibility, as 2-cycle engines have historically shown to be sensitive to variation in engine oils due to their own unique lubricant requirements. The 6V53T was chosen over other 2-cycle variants as it represents the highest power density two-cycle diesel engine in the Army's fleet. For this test, candidate oils must be able to provide adequate protection of the interface between the piston and liner surface to prevent cylinder scuffing, as well as protect the load bearing slipper bushings located between each connecting rod and articulated piston assembly. The DDC 6V53T is a 318C.I., turbo-supercharged, non-intercooled, direct injected, V6 diesel engine. Fueling is controlled through cam driven mechanical unit injectors, and the engine produces approximately 235hp using JP-8 fuel. The DDC 6V53T tested was configured as used in the M113A3 Armored Personnel Carrier (APC). A MIL-PRF-2104H oil evaluation was completed prior to SCPL testing to establish a current baseline for revised SCPL candidate comparison. Following the baseline, each revised candidate SCPL was tested to determine performance with respect to engine wear, oil life expectancy, and deposit formation.

In addition, each revised candidate SCPL was also evaluated in the American Society of Testing Methods (ASTM) D5966-10 roller follower wear test. This test evaluates a lubricants ability to protect roller follower valve train components from wear in high load at low to moderate engine speed scenarios. This test utilizes a General Motors (GM) 6.5L(NA) diesel engine which is the basis of GEP family of engines powering the HMMWV, and specifically monitors critical roller axle wear on the hydraulic lifters.

2.2 TRANSMISSION COMPATIBILITY

In addition to engine crankcase applications, the SCPL is intended to be used in power shift transmissions where MIL-PRF-2104 products are currently utilized. To ensure revised SCPL candidate compatibility in these applications, several industry established standardized transmission tests were completed to assess each of the candidates' frictional properties. These tests included:

- Caterpillar TO-4
  - Sequence 1220 – Sintered Bronze
  - Sequence 1222 – Wheel Brake Paper
- Allison C4
  - High Energy Friction – Graphite
  - High Energy Friction – Paper
- John Deere Qualification
  - JDQ-96 Wet Brake (abbreviated 1k cycles)

From these standardized transmission tests, revised candidate SCPL results could be compared to automatic transmission fluid (ATF) reference tests and past results of current MIL-PRF-2104 products. As with current MIL-PRF-2104 products, it is expected that the utilization of formulated engine oils in powershift transmission applications could forfeit some of the refined benefits of a purpose built ATF. Although these refinements are good goals for the SCPL, the primary requirement for candidates in these tests was to ensure that adequate performance was retained (i.e., acceptable frictional properties, torque capacity, protection, etc), and that the SCPL would meet or exceed the performance of MIL-PRF-2104 oils currently in utilization. Operator feel and noise, vibration, and harshness (NVH) effects are important in the commercial formulation of an ATF, but are of lesser concern to the military in comparison to overall functionality and durability of the equipment.

2.3 ENGINE FUEL CONSUMPTION IMPROVEMENT

Revised SCPL candidate lubricants were also evaluated for fuel consumption changes using a GEP 6.5L(T) diesel engine dynamometer test. Consistent with testing under Part 1, the cycle used to measure fuel consumption changes evaluated each lubricant over a range of load points and oil sump temperatures derived from previously acquired data from HMMWV operation at Ft. Hood, TX [8]. Unlike testing completed during Part 1 that used both new and “aged” lubricants to determine fuel consumption changes, only the new lubricants were tested on the revised candidate evaluations.

3.0 DISCUSSION OF RESULTS

The following sections outline and discuss test results acquired during revised candidate testing of the SCPL. These include: revised candidate chemical and physical analysis results, engine compatibility and oil endurance testing (includes GEP 6.5L(T), DDC 6V53T, and ASTM D5966 RFWT), standardized transmission compatibility tests, and fuel consumption improvement quantification.

3.1 SCPL CANDIDATE CHEMICAL & PHYSICAL PROPERTIES

Each revised SCPL candidate received was initially tested to document its chemical and physical properties to determine how closely it aligned with the goals of the SCPL. Analytical test results from each revised SCPL candidate can be seen in Table 1. Results from their respective initial candidates from Part 1 were included into the table for comparison. Observations from the analyses are listed below:

- Both revised candidates appear to have a slightly increased viscosity from the initial candidates, but still classify as an SAE 0W20 viscosity grade lubricant
- NOACK volatility increased for both candidates outside of the desired range as stated in the original request for experimental products (target 10%, minimum acceptable 11%)
- Shear stability improved for LO268869, remained consistent with LO271510
- All other properties were comparable from initial to revised candidate

Table 1. Baseline & SCPL Candidate Preliminary Chemical & Physical Properties

-	-	-	-	Initial Candidates (Part 1)		Revised Candidates (Part 2)	
-	-	-	-	a	b	a	b
-	-	-	-	LO-253071	LO-251746	LO-268869	LO-271510
Method	**Temp**	**Property**	**Units**				
D445	**-40°C**	**Viscosity**	cSt	7661.6	11158	14798.2	12885.34
D445	**40°C**	**Viscosity**	cSt	43.36	42.52	47.39	45.34
D445	**100°C**	**High Temp Viscosity**	cSt	8.42	8.13	8.6	8.49
D445 LT	**-48°C**	**Low Temp Viscosity**	cSt	36325.09	38427.23	27003.4*	**
D2983	**-40°C**	**Brookfield Viscosity**	cPs	10878	11158	12517	11917
D4683 TBS	**150°C**	**Tapered Bearing Shear Viscosity**	cPs	2.69	2.59	2.73	2.68
D4684	**-40°C**	**Apparent Viscosity**	mPa/s	10300	10000	12000	11000
D5293 COLD	**-35°C**	**Cold Cranking**	mPa/s	4190	4070	4864	4319
D5800		**Noack Volitility**	wt%	10	12.4	12	14.3
D7109	**100°C**	**Shear Stability**					
		Viscosity @ 100C after 30 Passes	cSt	8.33	8.11	8.59	8.43
		Viscosity loss after 30 Passes	% Loss	1.07	0.25	0.12	0.71
		Viscosity @ 100C after 90 Passes	cSt	8.22	8.07	8.55	8.47
		Viscosity loss after 90 Passes	% Loss	2.38	0.74	0.58	0.24
D97		**Pour Point**	°C	-60	<-60	<-63	<-60

*Results is suspect. No re-test results available.

**Initial sample found too viscous to obtain repeatable results. Re-test conducted by lube supplier yielded 47,939 cSt.

3.2 GEP 6.5L(T) ENGINE DURABILITY TESTING

The following section discusses the results obtained during the GEP 6.5L(T) engine durability portion of the SCPL development. Focus areas include construction of the engine durability test stand, description of the test cycle, and the revised SCPL candidate evaluation results (used oil analysis, engine metrology, and deposit ratings).

3.2.1 Test Stand Construction

The same GEP 6.5L(T) high temperature engine oil endurance test stand constructed during Part 1 of the SCPL development was used to evaluate each revised candidate during Part 2. As previously discussed, the GEP 6.5L(T) diesel engine was selected for SCPL evaluations due to its high severity on engine lubricants, and its high density in the military's tactical wheeled fleet. The GEP 6.5L(T) engine utilized for testing was purchased directly from General Engine Products, a subsidiary of AM General, the original equipment manufacturer (OEM) for the HMMWV. The 2HT GEP 6.5L(T) engine model tested is rated at 190 hp at 3400 rpm, and 380 lb-ft at 1800 rpm using diesel fuel. When utilizing JP-8, as was the case during the SCPL testing, power levels typically drop to around 170 hp and 320 lb-ft of torque at their respective peaks. To serve as a consistent test bed, this dedicated engine test stand was built to complete all of the high temperature evaluations for each initial and revised SCPL candidates. A picture of the GEP 6.5L(T) engine installation can be seen in Figure 1.

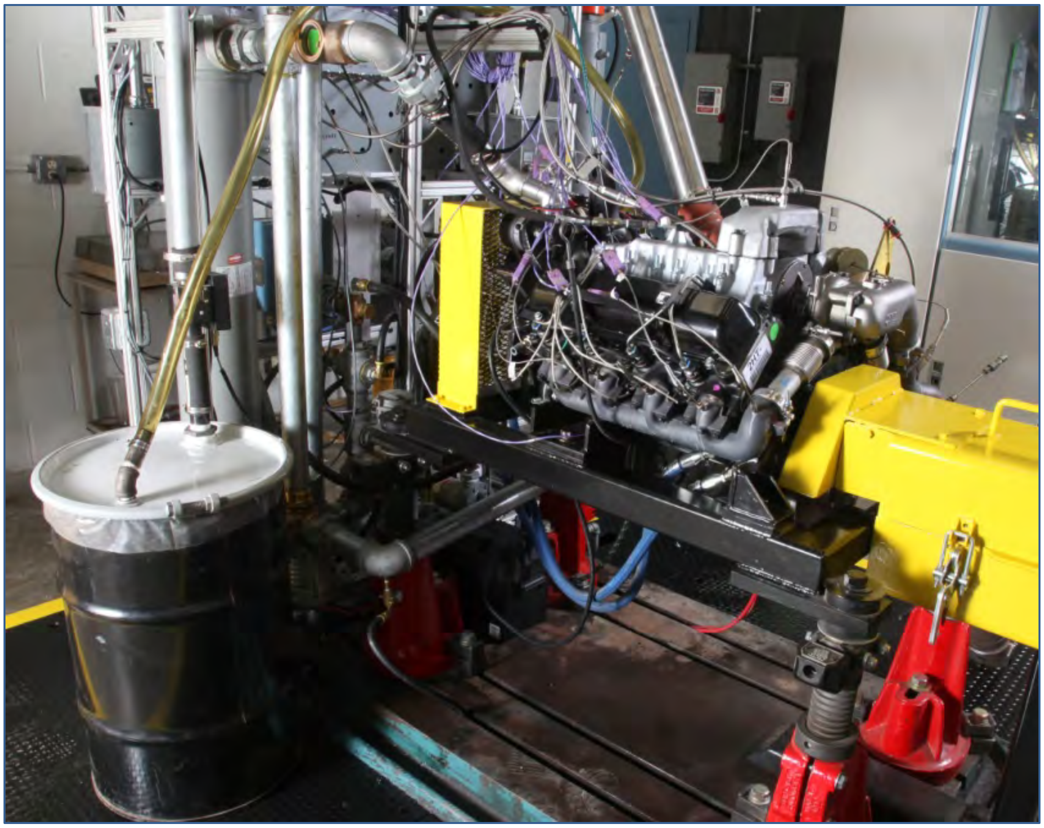

Figure 1. General Engine Products 6.5L(T) Test Cell Installation

The 6.5L(T) engine was mounted in a test cell at TFLRF with an engine dynamometer and equipped with all necessary ancillary equipment to operate the engine, with the exception of accessory equipment that would be installed and utilized in a vehicle (i.e., alternator, cooling fan, etc.). The bulleted list below outlines the basic hardware configuration utilized on the GEP 6.5L(T) engine dyno evaluations:

- The engine used SwRI developed PRISM data acquisition software to monitor and control engine operation throughout testing. Monitored engine parameters included all critical temperatures, pressures, and flow rates, as well as the engine's speed and output power/torque.
- Engine loading was provided by an eddy current engine dynamometer and an electro mechanical throttle actuation system. The dynamometer controlled overall engine speed, while the throttle actuation system adjusted the injection pump's rack position via a throttle cable to the injection pump rack.

- Liquid-liquid heat exchangers were used to regulate the engine water jacket and oil sump temperatures with building supplied process water.
- Fuel was supplied from bulk storage tanks to an engine “day-tank” that served as a common location for the engine supply and return lines. The engine’s fuel consumption was monitored by a coriolis flow meter for measuring the make-up fuel required to maintain the day tank at a constant volume.
- Inlet fuel temperature was controlled by a secondary heater control loop to maintain steady temperatures throughout testing. The control loop maintained a reservoir of a glycol-water solution at a specified temperature, and was then used as a heat source to elevate the incoming fuel to the desired set point through a liquid-liquid heat exchanger.
- Engine inlet air was drawn past a chilled water core to lower intake air temperatures prior to the engine air filtering system. This was required to maintain exhaust gas temperatures at safe levels during the long segments of continuous operation at rated speed and load during the test cycle. Air was filtered through an OEM-style air filter housing with an adjusting valve to vary intake air depression prior to the turbocharger inlet.
- Engine exhaust gases were ducted into an exhaust ventilation system integrated into the engine laboratory building. Back-pressure was controlled through a butterfly valve located in the exhaust stack prior to the buildings common exhaust header exiting the test cell.
- Engine blow-by gases were ducted into a drum to capture any entrained oil, and then vented through a hot-wire flow meter to monitor engine blow-by rates. Waste gases were then ducted to the buildings exhaust ventilation system at ambient pressure (to not effect crankcase pressure) to expel blow-by gasses from the test cell.
- Engine coolant was a 60/40 blend of ethylene glycol and de-ionized water.
- Fuel used during testing was JP-8 blended at location from commercially available Jet A with a double max-treat rate of lubricity enhancer DCI-4A. (Appendix G).

3.2.2 Test Cycle Operation

Consistent with Part 1, the test cycle used for revised candidate evaluations was a modified version of the 210 hour Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test [9]. At time of its

publishing, the standard 210 hour tactical wheeled vehicle laboratory engine cycle was correlated to 20,000 miles of actual military vehicle proving ground operation. For SCPL testing, modifications were made to the test temperature specifications to further increase the severity on the oil being tested in an effort to raise the standards for the baseline and candidate tests. Test termination would occur at the completion of the scheduled 210 hours, or upon major oil degradation, which ever occurred first. The test cycle consisted of alternating between two hours at rated speed and load followed by one hour at no-load idle. This was completed for 14 hours daily, followed by a 10 hour engine-off soak period to allow time for chemical reactions to take place in the oil sump. Engine oil temperatures were elevated during rated speed and load test conditions to simulate high ambient temperatures typical of desert operations. During no-load idle steps, engine temperatures (oil sump and coolant) were lowered to stress the lubricant through thermal cycling. The critical engine operating parameters controlled throughout testing are specified in Table 2. For consistency, engine output torque was controlled to a value of 256 lb-ft of torque for each test. This is a slight reduction of the typical total capable torque output of the GEP 6.5L(T), but was selected so that any full load output variation between test engines would not bias any single SCPL evaluation. To target this output torque, the throttle actuation control system would slightly back off of the injection pump rack position to meet the specified output, and control it over the test duration. This provided a consistent loading of all the internal engine components, so that each lubricant tested would be subjected to the same internal engine conditions as possible. The oil sump temperature specification of 260 °F for the rated speed and load step was selected based off a 4% increase in general requirement for MIL-PRF-2104 lubricants to be capable of continuous operation at 250 °F. This further stressed the SCPL candidates ability to control engine oil oxidation, which is a function of time at elevated temperatures. Coolant jacket outlet temperature during the rated speed and load step was maintained at 205 °F to maintain engine integrity throughout the test cycle.

Table 2. Tactical Wheeled Vehicle Test Cycle Operating Conditions

Parameter	Rated Speed & Load	No-Load Idle
Engine Speed [RPM]	3400 +/- 25	900 +/- 25
Engine Output Torque [lb-ft]	256 +/- 5	Not specified
Water Jacket Out [°F]	205 +/- 5	100 +/- 5
Oil Sump [°F]	260 +/- 5	125 +/- 5

Used engine oil samples were collected every 14 hours for chemical and physical analysis. These data were used to assess the condition of the lubricant and to determine test termination if necessary. Tests conducted on daily samples are outlined below in Table 3. The oil level of the engine was replenished daily after sampling to restore it to its proper level. All engine oil additions and samples were weighed throughout testing to track engine oil consumption.

Table 3. Used Oil Analysis Tests

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

3.2.3 Engine Metrology and Ratings

Each revised SCPL evaluation started with a new GEP 6.5L(T) engine. Prior to testing, each engine was disassembled to complete a pre-test inspection and metrology process. Engines were inspected for manufacturing defects (corrected as needed), and measurements of critical engine components were taken to document pre-test engine condition. These pre-test metrology procedures included measurements of:

- Crankshaft main bearing mass
- Connecting rod bearing mass
- Top, second, and bottom piston ring mass
- Top, and second piston ring radial thickness
- Piston ring end gap (in block)
- Piston skirt diameter

Piston bore diameter (measured top, mid, and bottom of bore in the transverse and longitudinal directions)

After the inspection and metrology process was completed, engines were reassembled according to factory specifications. During assembly, parts requiring lubrication were assembled using an additive free assembly lubricant. This is consistent with many ASTM standardized tests procedures, as to remove any bias on subsequent lubricant test data.

At the completion of each endurance test, the engine was once again disassembled and inspected. This allowed for documentation of wear experienced over the test duration. Since each test was terminated based on used oil condition and not operated for a fixed period of time, straight across comparisons of engine wear for each lubricant from metrology measurements cannot be completed. Many wear parameters are a function of total engine operation time, with the lubricant condition having a smaller impact. For example, ring wear experienced in an 84 hour test cannot be directly compared to a 140 hour test due to the difference in test length. Regardless, metrology measurements still prove useful in showing indications of overall wear patterns, and help to identify any large outliers during testing. Similar to pretest metrology, post-test procedures included measurements of:

- Crankshaft main bearing mass
- Connecting rod bearing mass
- Top, second, and bottom piston ring mass
- Top, and second piston ring radial thickness
- Piston ring end gap (in block)
- Piston skirt diameter
- Piston bore diameter (measured top, mid, and bottom bore in the transverse and longitudinal direction)

In addition to post-test metrology, engine pistons and valves received deposit ratings to quantify the amount and location of carbonaceous and lacquer type deposits present. This process was

completed following industry standardized ASTM deposits and rating procedures [10]. This was done to quantify the overall cleanliness of the lubricant and its ability to control harmful engine deposits when tested under severe conditions.

3.2.4 Revised Candidate Evaluation Results

Table 4 shows the engine operating summary for each revised SCPL candidate run during the rated speed and load step compared to its initial candidate evaluation. This shows the consistency that was achieved between the two revised candidate evaluation tests, and the initial candidates evaluated during Part 1. For both revised candidates, the overall averaged torque was slightly below the target 256 lb-ft, but within the +/- 5 lb-ft repeatability margin. Due to variation in absolute engine output between each production based engine, some engines only marginally meet the 256 lb-ft target at the start of testing, and upon oil aging and thickening within the crankcase, the engine output power/torque would begin to drop below the threshold. This small variation in engine torque output is not considered to have biased these evaluations, as overall engine oil sump temperature is expected to be the driving factor in lubricant degradation. The consistency achieved for the more critical engine oil sump temperature can be seen in Table 4.

Table 4. SCPL Revised Candidate Evaluations, Rated Engine Operation Summary

		LO253071 Initial Candidate **Rated Conditions (3400 RPM)**		LO268869 Revised Candidate **Rated Conditions (3400 RPM)**		LO251746 Initial Candidate **Rated Conditions (3400 RPM)**		LO271510 Revised Candidate **Rated Conditions (3400 RPM)**	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.02	0.82	3400.01	0.73	3400.00	0.72	3400.01	0.76
Torque*	lb-ft	251.40	4.43	253.98	2.61	256.24	1.74	254.23	2.88
Fuel Flow	lb/hr	82.51	1.06	79.24	0.79	77.86	0.89	80.52	0.83
Power*	bhp	162.74	2.87	164.42	1.68	165.88	1.11	164.58	1.86
BSFC*	lb/bhp*hr	0.507	0.012	0.482	0.007	0.469	0.006	0.489	0.006
Temperatures:									
Coolant In	°F	190.31	0.92	190.06	1.09	191.39	0.73	190.40	0.92
Coolant Out	°F	205.00	0.84	205.00	1.01	204.99	0.66	204.99	0.84
Oil Sump	°F	260.02	0.41	260.05	0.44	259.96	0.37	260.05	0.50
Fuel In	°F	95.00	0.31	95.02	0.31	95.01	0.33	95.01	0.34
Intake Air	°F	69.72	4.99	74.94	3.62	69.95	2.24	68.33	3.34
Cylinder 1 Exhaust	°F	1148.60	9.38	1136.32	15.48	1098.38	14.59	1135.40	16.16
Cylinder 2 Exhaust	°F	1104.56	14.95	1204.35	10.67	1158.88	18.88	1205.01	13.90
Cylinder 3 Exhaust	°F	1216.91	13.84	1186.67	14.53	1224.78	31.99	1206.48	16.88
Cylinder 4 Exhaust	°F	1158.22	17.08	1141.38	14.00	1115.13	16.48	1144.29	15.49
Cylinder 5 Exhaust	°F	1173.29	9.48	1152.53	16.09	1181.29	25.83	1162.88	14.26
Cylinder 6 Exhaust	°F	1206.17	21.87	1162.03	13.27	1118.51	17.07	1166.94	17.23
Cylinder 7 Exhaust	°F	1133.30	10.52	1150.77	14.52	1123.50	19.87	1144.28	18.44
Cylinder 8 Exhaust	°F	1189.49	23.12	1147.97	11.32	1144.84	18.46	1164.26	13.81
Pressures:									
Oil Galley	psi	34.70	0.74	35.94	0.56	37.13	0.99	36.96	1.59
Ambient Pressure	psiA	14.25	0.05	14.26	0.05	14.23	0.04	14.30	0.07
Boost Pressure	psi	4.95	0.11	4.32	0.08	3.96	0.09	4.84	0.12

* Non-corrected Values

Figure 2 shows the TAN/TBN response of each revised candidate and its respective initial evaluation. Revised candidate LO268869 showed a large improvement in TAN/TBN control compared to its initial evaluation (LO253071). The TAN/TBN cross over for its evaluation occurred approximately 50 hours later in the test cycle, and the useful lubricant life was extended by over 80 hours. Revised candidate LO271510 showed a smaller improvement over its initial evaluation (LO251746), but still extended the useful lubricant life by 28 hours. Although this improvement was smaller, the performance achieved by its initial candidate (LO251746) was greater than that shown by LO268869's initial candidate during Part 1, so less change was expected overall. Despite the improvement shown by candidate LO271510, it still did not reach the full 210 hour test target, with testing being terminated at 196 hours due to oil condition. From comparing the slopes of the TAN/TBN curves for LO271510 to its initial evaluation (LO251746), it appears that the formulation changes had little impact on the oils overall ability to resist degradation, resulting in similar degradation rates being observed during both evaluations. In the end, the used oil condition of LO268869 at EOT is more favorable than that of LO271510.

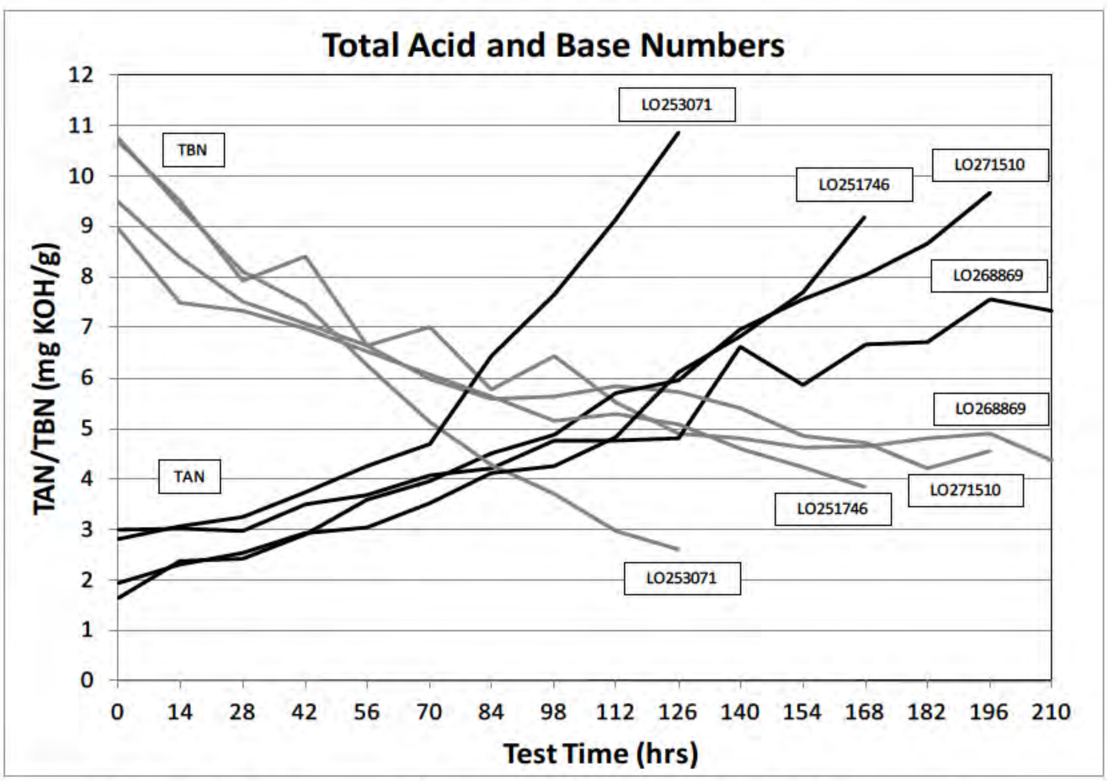

Figure 2. SCPL Revised Candidate Evaluations, TAN/TBN Response

Like the TAN/TBN results, the used oil oxidation and nitration curves presented in Figure 3 show similar trends. LO268869 showed the largest improvement over its initial candidate (LO253071) with an approximate 50% reduction in overall oxidation at end of test (EOT). LO271510 showed overall similar oxidation rates as its initial candidate (LO251746) testing which resulted in a slightly higher end of test oxidation rate due to the extended length of operation.

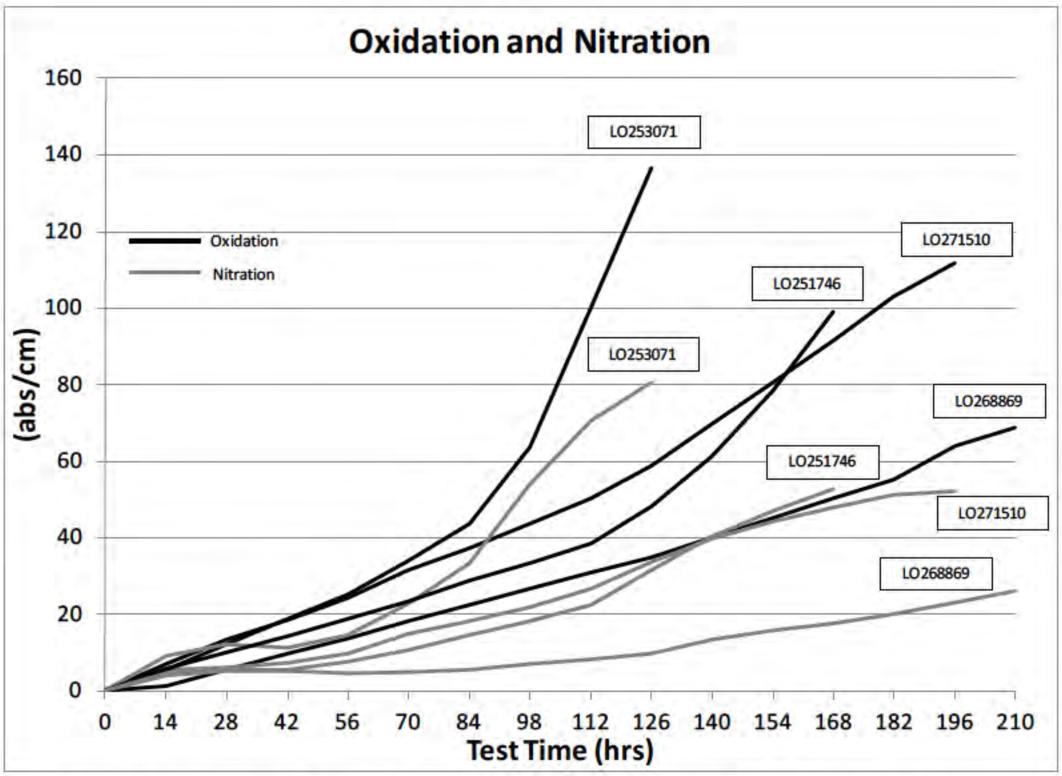

Figure 3. SCPL Revised Candidate Evaluations, Oxidation and Nitration Response

Figure 4 shows the lead and copper wear metal accumulations for the initial and revised SCPL evaluations. As before, revised candidate LO268869 showed much improvement from its initial evaluation (LO253071,) in which the initial candidate broke early in the test and experienced rapid accumulation of lead (Pb) and copper (Cu) wear metals topping 500 ppm and 300 ppm respectively. These wear metals are indicative of main bearing and connecting rod bearing distress, and serve as a good litmus test for this engine to monitor how well an oil is protecting critical engine components. During the LO268869 revised candidate evaluation, the overall oil condition remained favorable, which showed in these reduced key wear metals that remained under 100 ppm for over the entire 210 hour duration. Conversely, revised candidate LO271510 showed effectively no change in wear metal accumulation rates from its initial evaluation. This resulted in an overall higher total accumulation by the end of testing due to the increased test length. Lead wear metals in this evaluation approached 250 ppm at EOT.

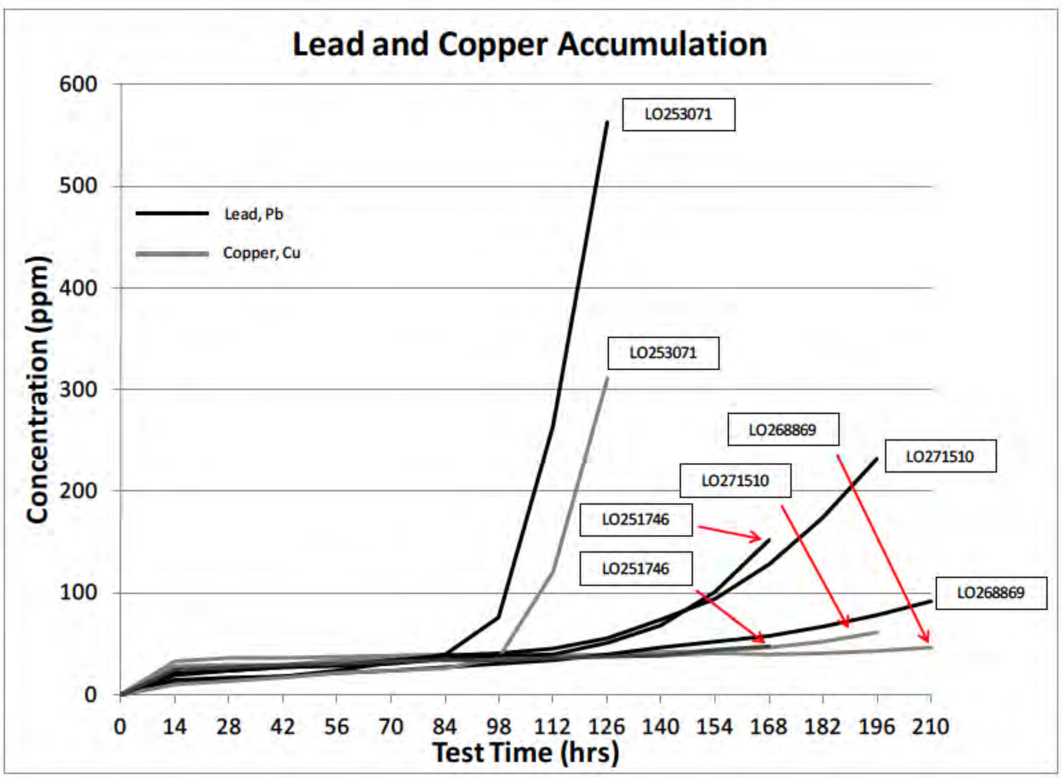

Figure 4. SCPL Revised Candidate Evaluations, Lead and Copper Accumulation

Table 5 shows the overall accumulated oil consumption rates for the revised and initial SCPL evaluation runs. Hourly consumption rates for each revised candidate were in line with what was seen previously in Part 1. Both revised candidates showed a slightly higher consumption rate than their initial evaluation. This is likely attributed to the increased volatility that both revised candidates showed over their initial submittals.

Table 5. SCPL Candidate Evaluations, Accumulated Oil Consumption Rate

	LO253071	LO268869	LO251746	LO271510
Engine Oil Consumption [lb/hr]	0.069	0.081	0.072	0.084

Table 6 shows the main bearing mass changes for each of the revised and initial SCPL candidate evaluations. As reported during Part 1, the number three thrust bearing mass is omitted from calculations. This is due to a large variation in thrust surface wear on the number three main bearing from loading attributed to interactions between the dynamometer and engine coupling. From past experience, these varying thrust loads applied during testing have resulted in inconsistent thrust surface wear which biases main bearing mass change measurements. Both maximum and average weight change for the remaining bearings were increased from their initial evaluations. Although unusual, the overall values still fall within the range of variations (0.03 to 0.15 grams) seen during the MIL Spec and commercial 15W-40 oil evaluations completed during Part 1, and thus are not considered out of line.

Table 6. SCPL Revised Candidate Evaluations, Main Bearing Mass Changes, grams

		Main Bearing Mass Changes (grams)			
		initial	*revised*	*initial*	*revised*
Main Bearing	**Shell**	**LO253071**	**LO268869**	**LO251746**	**LO271510**
1	Top	0.0171	0.0471	0.0257	0.0328
	Bottom	0.0146	0.0983	0.0237	0.0581
2	Top	0.0205	0.0323	0.0240	0.0319
	Bottom	0.0891	0.2106	0.0338	0.2133
3	Thrust Bearing Excluded From Calculations				
4	Top	0.0124	0.0272	0.0293	0.0359
	Bottom	0.0385	0.1414	0.0305	0.1148
5	Top	0.0777	0.0603	0.0411	0.0563
	Bottom	0.1066	0.0934	0.0830	0.1152
	Maximum	0.1066	0.2106	0.0830	0.2133
	Average	0.0471	0.0888	0.0364	0.0823

Table 7 shows the connecting rod bearing mass changes for the revised and initial SCPL candidate evaluations. Average and maximum connecting rod bearing mass changes for the revised SCPL evaluations were reduced from their initial evaluations, and result in some of the lowest values seen compared to the previous testing completed during Part 1 (0.02 to 0.04 gram variation).

Table 7. SCPL Revised Candidate Evaluations, Connecting Rod Bearing Mass Changes, grams

		Rod Bearing Mass Changes (grams)			
		initial	*revised*	*initial*	*revised*
Rod Bearing	**Shell**	**LO253071**	**LO268869**	**LO251746**	**LO271510**
1	Top	0.1668	0.0239	0.0339	0.0131
	Bottom	0.0598	0.0106	0.0347	0.0165
2	Top	0.0289	0.0172	0.0147	0.0157
	Bottom	0.0374	0.0088	0.0177	0.0134
3	Top	0.0520	0.0473	0.0239	0.0231
	Bottom	0.0540	0.0361	0.0290	0.0070
4	Top	0.0135	0.0175	0.0431	0.0165
	Bottom	0.0082	0.0124	0.0695	0.0105
5	Top	0.0316	0.0275	0.0158	0.0136
	Bottom	0.0612	0.0134	0.0155	0.0139
6	Top	0.0338	0.0264	0.0454	0.0127
	Bottom	0.0342	0.0153	0.0703	0.0078
7	Top	0.0139	0.0250	0.0664	0.0169
	Bottom	0.0188	0.0189	0.0564	0.0178
8	Top	0.0115	0.0142	0.0416	0.0164
	Bottom	0.0098	0.0130	0.0542	0.0165
	Maximum	0.1668	0.0473	0.0703	0.0231
	Average	0.0397	0.0205	0.0395	0.0145

Table 8 shows the camshaft lobe peak surface variation for each of the revised and initial SCPL candidate evaluations. From testing completed during Part 1, a typical range of 1.4 to 1.9 microns was established as normal. During its initial evaluation, candidate LO253071 showed an unusually high value of 3.1 micron variation, but its revised candidate LO268869 improved on this and brought total average variation in line with normally expected values yielding a total variation of 1.7 microns. Revised candidate LO271510 also improved from its initial (LO251746) evaluation, and showed the lowest variation seen to date at 1.1 microns. This suggest that both revised candidates are adequately protecting the camshaft from wear.

Table 8. SCPL Revised Candidate Evaluations, Cam Lobe Peak Surface Variation

Cam Lobe Waviness Parameter [μm]				
	initial	*revised*	*initial*	*revised*
Cam Lobe	LO253071	LO268869	LO251746	LO271510
1	3.49	1.73	1.74	1.07
2	3.00	1.24	1.47	0.95
3	3.80	1.47	1.60	0.92
4	2.79	1.17	1.58	1.32
5	2.24	1.66	1.38	0.83
6	2.40	2.21	1.94	1.44
7	2.78	1.82	1.46	1.01
8	3.37	1.31	2.25	1.23
9	5.34	2.24	1.53	1.18
10	2.97	1.43	1.92	1.03
11	2.39	0.91	1.41	1.06
12	4.16	1.24	3.33	1.05
13	3.04	2.06	1.72	1.10
14	2.44	2.98	1.49	1.14
15	3.10	1.59	1.54	1.25
16	2.06	1.42	1.67	1.02
Maximum	5.34	2.98	3.33	1.44
Average	3.09	1.66	1.75	1.10

Table 9 shows the ring pack mass loss for each of the revised and initial SCPL candidate evaluations. Average and maximum weight loss changes for both revised SCPL candidates were generally in line with what was seen during the initial evaluations (Note: for candidate LO251746 piston number 8 oil control ring, mass loss shows as 0.5625 grams. This appears to be an isolated anomaly, and is not representative of the remaining oil control rings changes on pistons 1 through 7). Ring weight loss is predominately attributed to the overall viscosity of the lubricating fluid impacting the film thickness seen at the piston liner wall interface. Since the revised candidates did not have any significant viscosity change, no large changes were expected in the weight loss measurements.

Table 9. SCPL Candidate Evaluations, Piston Ring Mass Changes

Piston Ring Mass Changes					
		initial	*revised*	*initial*	*revised*
Cylinder	**Ring No.**	**LO253071**	**LO268869**	**LO251746**	**LO271510**
1	1	0.0678	0.1008	0.0768	0.0631
	2	0.0241	0.0313	0.0260	0.0234
	3	0.0160	0.0125	0.0154	0.0121
2	1	0.0661	0.0987	0.0875	0.0725
	2	0.0290	0.0366	0.0262	0.0273
	3	0.0160	0.0143	0.0135	0.0115
3	1	0.0790	0.0899	0.0914	0.0800
	2	0.0342	0.0391	0.0247	0.0308
	3	0.0198	0.0182	0.0167	0.0138
4	1	0.0676	0.0845	0.0857	0.0929
	2	0.0252	0.0338	0.0273	0.0296
	3	0.0163	0.0170	0.0191	0.0127
5	1	0.0740	0.1054	0.0786	0.0800
	2	0.0261	0.0437	0.0264	0.0234
	3	0.0182	0.0164	0.0190	0.0116
6	1	0.0993	0.0918	0.0937	0.1007
	2	0.0328	0.0392	0.0277	0.0252
	3	0.0223	0.0163	0.0173	0.0123
7	1	0.0635	0.0809	0.0905	0.0992
	2	0.0256	0.0333	0.0236	0.0317
	3	0.0188	0.0147	0.0129	0.0131
8	1	0.0828	0.0865	0.0716	0.1007
	2	0.0277	0.0311	0.0268	0.0263
	3	0.0186	0.0188	0.5625	0.0122
Maximum Ring 1		0.0993	0.1054	0.0937	0.1007
Maximum Ring 2		0.0342	0.0437	0.0277	0.0317
Maximum Ring 3		0.0223	0.0188	0.5625	0.0138
Average Ring 1		0.0750	0.0923	0.0845	0.0861
Average Ring 2		0.0281	0.0360	0.0261	0.0272
Average Ring 3		0.0183	0.0160	0.0846	0.0124

Lastly, Table 10 shows the 8 piston average deposit ratings for each of the revised and initial SCPL candidate evaluations. Overall deposit demerits of the revised candidates slightly increased from their initial evaluations. Total demerits were still well within ranges seen during testing completed in Part 1, and none of the deposits seen during the revised candidate evaluations would be considered excessive and harmful to engine operation.

Table 10. SCPL Candidate Evaluations, Piston Deposits

Piston Deposits				
Ratings	Cylinder Average			
	initial	*revised*	*initial*	*revised*
	LO253071	LO268869	LO251746	LO271510
Ring Sticking				
Ring No.1	No	No	No	No
Ring No.2	No	No	No	No
Ring No.3	No	No	No	No
Scuffing % Area				
Ring No.1	0	0	0	0
Ring No.2	0	0	0	0
Ring No.3	0	0	0	0
Piston Crown	0	0	0	0
Piston Skirt	0	0	0	0
Cylinder Liner, %	0	0	0	0
Piston Carbon, Demerits				
No.1 Groove	43.88	60.59	36.28	48.72
No.2 Groove	0.66	3.10	5.84	3.66
No.3 Groove	0.31	0.00	0.00	0.00
No.1 Land	36.50	44.38	36.31	34.63
No.2 Land	11.69	12.75	14.25	11.91
No.3 Land	0.00	0.34	0.88	0.41
Upper Skirt	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	1.56
Front Pin Bore	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits				
No.1 Groove	0.00	0.02	0.00	0.00
No.2 Groove	3.17	2.98	2.73	2.53
No.3 Groove	2.57	1.71	1.41	1.83
No.1 Land	0.05	0.07	0.02	0.03
No.2 Land	1.89	1.77	2.20	1.30
No.3 Land	2.37	2.08	1.21	1.79
Upper Skirt	0.34	0.63	0.54	0.65
Under Crown	2.95	3.64	4.77	3.86
Front Pin Bore	1.26	1.37	0.80	1.47
Rear Pin Bore	1.20	1.47	0.74	1.40
Total, Demerits	108.84	136.90	107.98	115.73
Miscellanous				
Top Groove Fill, %	38.63	56.63	28.50	40.13
Intermediate Groove Fill, %	0.00	2.38	2.13	1.50
Top Land Heavy Carbon, %	18.38	27.13	16.38	14.38
Top Lan Flaked Carbon, %	0.00	0.00	0.00	0.00
Valve Tulip Deposits, Merits				
Exahust	9.2	9.2	9.0	9.0
Intake	8.6	7.3	8.6	7.3

Full 6.5L(T) test report data from each revised candidate test (LO268869 and LO271510) can be seen in Appendix A1, and A2 respectively. Full test report data from each initial SCPL candidate can be found attached to TFLRF Interim Report 418, *Single Common Powertrain Development* [4].

3.3 2-Cycle Engine Compatibility Testing

The following section discusses the results obtained during the 2-cycle diesel engine compatibility portion of the SCPL development. Focus areas included construction of the engine test stand, description of the test cycle, and the baseline MIL-PRF-2104H 15W-40 and revised SCPL candidate evaluation results (metrology and deposit ratings).

3.3.1 Test Stand Construction

A DDC 6V53T engine test stand was constructed to evaluate SCPL compatibility with a 2-cycle diesel engine. Similar to the GEP 6.5L(T) testing, the same engine test stand was used to evaluate all of the lubricants for consistency. Evaluations included the current MIL-PRF-2104H 15W-40 OE/HDO to establish a known baseline condition (consistent with actual current military applications), followed by testing of the revised candidates LO268869 and LO271510. The DDC 6V53T was purchased new from the manufacturer through the local Detroit Diesel authorized dealer (Stewart and Stevenson LLC of San Antonio TX). The engine was configured in its military version, built according to the specifications for the current M113A3 APC. The DDC 6V53T as tested produced approximately 235hp and 560 lb-ft of torque using JP-8 fuel. A picture of the DDC 6V53T engine installation can be seen on the following page in Figure 5.

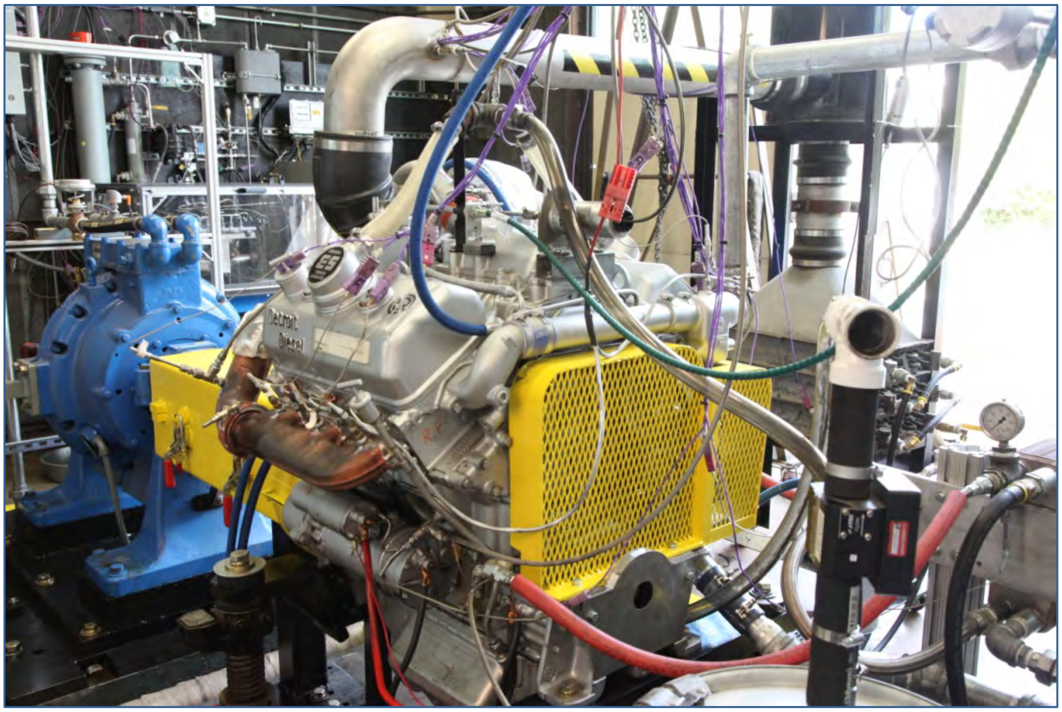

Figure 5. Detroit Diesel 6V53T Test Cell Installation

Like the GEP 6.5L(T), the 6V53T engine was mounted in an engine dynamometer test cell for SCPL testing and equipped with all necessary ancillary equipment to operate the engine, with the exception of accessory equipment that would be installed and utilized in a vehicle (i.e., alternator, cooling fan, etc.). The bulleted list below outlines the basic test stand configuration utilized in the SCPL engine oil test program:

- The engine used SwRI developed PRISM data acquisition software to monitor and control engine operation throughout testing. Monitored engine parameters included all critical temperatures, pressures, and flow rates, as well as engine speed and output power/torque.
- Engine loading was provided by an eddy current engine dynamometer and an electro mechanical throttle actuation system. The dynamometer controlled overall engine speed, while the throttle actuation system adjusted the rack position via a throttle cable to manipulate engine load.

- A liquid-liquid heat exchanger was used to regulate the engine water jacket temperature with building supplied process water.

- The oil filter housing and oil cooler was removed from the engine and their inlets and outlets were plugged. The original engine oil filter housing was then remotely mounted to the test stand and connected via steel braided Teflon hose to the engines oil filter outlet port. A remote liquid-liquid heat exchanger was then added in series with the stainless braided Teflon oil lines (after the oil filter), and its return was plumbed back to the engine via the engine's front lower cover. These modifications were completed to allow easier servicing of the engine's airbox covers for routine bore inspections during testing, as well as independent control of the engine oil sump temperature by removing the oil cooler from the engine water jacket. Changes made to the engine had no impact on its internal oiling/lubrication.

- Fuel was supplied from bulk storage tanks to an engine "day-tank" that served as a common location for the engine supply and return lines. The engine's fuel consumption was monitored by a coriolis flow meter for measuring the make-up fuel required to maintain the day tank at a constant volume.

- Inlet fuel temperature was controlled by a heater control loop to maintain steady inlet temperature throughout testing. The control loop maintained a reservoir of a glycol-water solution at a specified temperature, and was then used as a heat source to elevate the temperature of incoming fuel to the desired set point through a liquid-liquid heat exchanger.

- Engine inlet air was drawn past a chilled (process water) water core to lower intake air temperatures prior to the engine air filtering system. Air was filtered through an OEM-style air filter housing with an adjusting valve to vary intake air restriction prior to the turbocharger inlet.

- Engine exhaust gases were ducted into an exhaust ventilation system integrated into the engine laboratory building. Back-pressure was controlled via a butterfly valve located in the exhaust stack between the engine and the buildings common exhaust header before exiting the test cell.

- Engine blow-by gases were ducted into a drum to capture any entrained oil, and then vented through a hot-wire flow meter to monitor engine blow-by rates. Waste gasses were then ducted to the buildings exhaust ventilation system at ambient pressure (to not effect crankcase pressure) to expel blow-by gasses from the test cell.
- Engine coolant was a 60/40 blend of ethylene glycol and de-ionized water.
- Fuel used during testing was JP-8 blended at location from commercially available Jet A with a double max-treat rate of lubricity enhancer DCI-4A. (Appendix I)

3.3.2 Test Cycle Operation

The test cycle used for 2-cycle compatibility evaluations was based on procedures outlined in Federal Test Method Standard No. 791C, Method 355, Performance of Engine Lubricating Oils in a Two-Cycle Diesel Engine Under Cyclic, Turbo-Supercharged Conditions [11]. Some modifications were made to selected operating conditions as the engine output and torque characteristics of the current 6V53T model have changed since the original establishment of the test method. Despite this, the general operation of the engine test cycle remained unchanged. The test cycle included cyclic modes of 0.5 hours at idle, 2 hours at max power, 0.5 hours at idle, and 2 hours at max torque. This was repeated 4 times daily for a total of 20 hours runtime, accumulating 240 hours over a 12 day test. Daily operation was followed by a 4 hour engine off soak prior to the next day's running to allow thermal cycling of the lubricant. Similar to the GEP 6.5L(T), the cycle called out in this Federal Test Method was based off of work reported under CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test [9]. As with the tactical wheeled vehicle cycle, the report also outlined a 240 hour tracked vehicle cycle that was correlated at the time of its publishing to 4,000 miles of actual military tracked vehicle proving ground operation.

Prior to the start of testing, and upon completion of every 60 hours an engine airbox inspection was completed to assess the condition of the piston skirts, ring faces, and cylinder liner. This allowed a quasi real time monitoring of the oils performance in protecting critical engine components throughout the test duration. Bore inspections were completed by passing a borescope through the engines airbox and liner intake ports and rating the condition of the liner

surface. Per the procedure, if any single liner experienced greater than 30% scuffing while other liners remained in good condition, a single cylinder kit could be replaced and testing continued. This could only be completed once during the test cycle, otherwise testing was to be terminated. If at any time multiple liners experience severe scuffing, and was deemed progressive in nature, the test was to be terminated. Severe scuffing could potentially lead to failure of the liner O-ring and cause catastrophic engine damage.

During testing, engine oil sump and coolant temperatures were controlled to ensure test consistency and severity for each lubricant tested. No engine oil changes were made during the test cycle, and testing was continued until the completed 240 hours, or upon the occurrence of major oil degradation or liner scuffing. Table 11 below shows the operation conditions for the 6V53T testing.

Table 11. DDC 6V53T Operating Conditions

Parameter	Max Power	Max Torque	Idle
Engine Speed [RPM]	2800 +/- 25	1600 +/- 25	950 +/- 25
Water Jacket Out [°F]	170 +/- 5	170 +/- 5	170+/- 5
Oil Sump [°F]	245+/- 5	230 +/- 5	220 +/- 5

Used engine oil samples were collected every 20 hours for analysis. These samples were used to assess the condition of the lubricant and to determine test termination if necessary. Extreme liner scuffing could also be identified by sharp changes in iron accumulation rates in the used oil. Tests conducted on daily samples are outlined below in Table 12. Engine oil level was replenished daily after sampling to restore its capacity. All engine oil additions and samples were weighed throughout testing to track engine oil consumption.

Table 12. Used Oil Analysis Tests

Test Method	Description
ASTM D445	Kinematic Viscosity @ 100 °C
ASTM D4739	Total Base Number
ASTM D664	Total Acid Number
ASTM D5185	Wear Metals by ICP

3.3.3 Engine Metrology and Ratings

Each lubricant was evaluated using the same DDC 6V53T engine after completing an "in-frame" rebuild. The primary item of focus for 2-cycle compatibility was the engines liner and piston, commonly referred to as the cylinder kit. Each cylinder kit underwent a metrology process before use to fully document its starting condition prior to build up. The pre-test metrology process included measurements of the cylinder kit, as well as other critical engine parameters to ensure integrity of the engine.

Pre-test metrology included:

- Piston ring clearances (end gap & side clearance, all)
- Top, second, and third ring radial thickness
- Piston ring mass, all
- Upper oil control ring and expander tension (reference only measurement)
- Piston skirt diameter
- Liner bore (free standing, T/AT & F/B) at:
  - 13 mm from top
  - 25 mm above ports
  - 25 mm below ports
  - 13mm from bottom
- Liner surface finish (single pass above ports)
- Engine block bore (top & bottom, T/AT & F/B)
- Slipper bushing tin plate thickness (reference only measurement)
- Slipper bushing mass
- Connecting rod bearing mass
- Connecting rod bearing to crank journal clearance
- Exhaust valve recession
- Crankshaft endplay

After the inspection and metrology process was completed, the engine was reassembled according to factory specifications. As with the 6.5L(T) testing, any parts requiring lubrication during assembly were lubricated using an additive free lubricant in order to remove any bias on subsequent lubricant test data.

At the completion of each test, the engine was again disassembled and inspected. This allowed for documentation of wear experienced over the test duration, and assessment of the piston skirt, rings, and liner condition. Similar to pretest metrology, post-test metrology procedures included measurements of:

- Piston ring clearances (end gap only, all)
- Top, second, and third ring radial thickness
- Piston ring mass, all
- Piston skirt diameter
- Liner bore (free standing, T/AT & F/B) at:
    - 13mm from top
    - 25mm above ports
    - 25mm below ports
    - 13mm from bottom
- Slipper bushing mass
- Connecting rod bearing mass

In addition to metrology, critical engine components received post-test ratings to quantify the amount and location of carbonaceous and lacquer type deposits present, and wear experienced during testing. Like the 6.5L(T) testing, this process was completed following industry standardized ASTM ratings procedures [10]. Ratings included piston deposits, ring face distress, piston skirt and liner ratings, intake port plugging, and slipper bushing exposed copper.

3.3.4 MIL-PRF-2104H and Revised Candidate Evaluation Results

Each of the MIL-PRF-2104H 15W-40 and revised SCPL candidate tests completed the 240 hours test cycle in the 6V53T without experiencing major oil degradation or severe liner scuffing. Due to the DDC 6V53T's comparatively lower engine oil sump temperatures and higher overall oil consumption compared to that of the GEP 6.5L(T), the used engine oil condition did not exhibit much degradation throughout each test. As a result, used oil analysis comparisons were uneventful, and detailed comparison was excluded from discussion. Full used oil analysis for each test can be reviewed in the respective test reported attached as appendices to this report.

As previously stated, engine metrology was completed during pre and post test activities to document overall engine wear and to assess the oil's ability to protect critical engine components. Table 13 and Table 14 show the average liner bore diameter change and piston to liner clearance change for each of the SCPL revised candidates and the baseline MIL-PRF-2014H 15W-40 evaluation. Average liner bore diameter changes from start to end of testing were within two-ten thousands (0.0002″) of an inch for all tests. Similarly, the piston to liner clearance remained within four-ten thousands (0.0004″) of an inch. Overall, the SCPL candidates provided comparable piston and liner protection as the current MIL-PRF-2104H products in 2-cycle applications. (Note- For candidate LO268869, liner 3L was inadvertently split for ratings prior to the post-test liner bore diameter measurements, thus measurements were not made).

Table 13. DDC 6V53T Average LinerBore Diameter Changes, Baseline & SCPL Revised Candidates.

MIL-PRF-2104H 15W40		
Cylinder	Avg Bore DIA Change	Out of Round
1L		0.0004
	0.0003	0.0004
		0.0001
		0.0000
2L		0.0001
	0.0002	0.0001
		0.0001
		0.0001
3L		0.0004
	0.0002	0.0000
		0.0000
		0.0005
1R		0.0001
	0.0003	0.0001
		0.0002
		0.0003
2R		0.0005
	0.0003	0.0000
		0.0002
		0.0004
3R		0.0003
	0.0003	0.0002
		0.0003
		0.0006
Average All Cylinders	0.0002	

Candidate LO268869		
Cylinder	Avg Bore DIA Change	Out of Round
1L		0.0012
	0.0004	0.0003
		0.0001
		0.0003
2L		0.0005
	0.0003	0.0002
		0.0000
		0.0003
3L		N/A
	N/A	N/A
		N/A
		N/A
1R		0.0006
	0.0003	0.0001
		0.0000
		0.0003
2R		0.0002
	0.0002	0.0002
		0.0003
		0.0002
3R		0.0004
	0.0002	0.0001
		0.0002
		0.0001
Average All Cylinders	0.0003	

Candidate LO271510		
Cylinder	Avg Bore DIA Change	Out of Round
1L		0.0003
	0.0002	0.0004
		0.0004
		0.0001
2L		0.0002
	0.0002	0.0001
		0.0000
		0.0001
3L		0.0002
	0.0003	0.0001
		0.0001
		0.0003
1R		0.0004
	0.0002	0.0003
		0.0002
		0.0001
2R		0.0000
	0.0002	0.0000
		0.0000
		0.0003
3R		0.0003
	0.0003	0.0001
		0.0001
		0.0000
Average All Cylinders	0.0002	

Table 14. DDC 6V53T Piston to Liner Clearance Changes, Baseline & SCPL Revised Candidates

MIL-PRF-2104H 15W40

	Cylinder	Piston to Liner Clearance	Change
Pre - Test	1	0.0058	
Pre - Test	2	0.0060	
Pre - Test	3	0.0059	
Pre - Test	4	0.0058	
Pre - Test	5	0.0059	
Pre - Test	6	0.0059	
Post - Test	1	0.0059	0.0002
Post - Test	2	0.0071	0.0010
Post - Test	3	0.0073	0.0015
Post - Test	4	0.0068	0.0011
Post - Test	5	0.0064	0.0005
Post - Test	6	0.0070	0.0010

Average	0.0009
Max	0.0015

Candidate LO268869

	Cylinder	Piston to Liner Clearance	Change
Pre - Test	1	0.0056	
Pre - Test	2	0.0046	
Pre - Test	3	0.0048	
Pre - Test	4	0.0067	
Pre - Test	5	0.0058	
Pre - Test	6	0.0063	
Post - Test	1	0.0068	0.0013
Post - Test	2	0.0065	0.0019
Post - Test	3	N/A	N/A
Post - Test	4	0.0078	0.0011
Post - Test	5	0.0072	0.0014
Post - Test	6	0.0069	0.0006

Average	0.0012
Max	0.0019

Candidate LO271510

	Cylinder	Piston to Liner Clearance	Change
Pre - Test	1	0.0052	
Pre - Test	2	0.0046	
Pre - Test	3	0.0057	
Pre - Test	4	0.0046	
Pre - Test	5	0.0055	
Pre - Test	6	0.0058	
Post - Test	1	0.0063	0.0011
Post - Test	2	0.0059	0.0013
Post - Test	3	0.0068	0.0012
Post - Test	4	0.0063	0.0017
Post - Test	5	0.0065	0.0011
Post - Test	6	0.0074	0.0016

Average	0.0013
Max	0.0017

The piston and liner metrology findings were in agreement with the ratings of these components. Table 15 shows the liner surface ratings. Each liner was rated to assess surface condition after being cut in half at the end of testing. Specifically, each liner was rated to quantify the percent area of polish or scuffing present. As seen below, each test had average values below 15% polish, and below 25% polish on any single liner. The revised SCPL candidates did show a slightly higher average polished area than that seen during the baseline 15W-40 test, but still remained relatively low. None of the post-test liners showed scuffing on their surfaces which supports that the revised candidate SCPL's are compatible for use in two-cycle diesel engine applications, and are providing comparable protection as the current MIL-PRF-2104H 15W-40.

Table 15. DDC 6V53T Cylinder Liner Ratings

		Cylinder Liner Ratings			
		% Polish		Total % Area Polished	
		T	AT		
MIL-PRF-2104H 15W40	1L	8	3	11	
	2L	0	10	10	
	3L	7	4	11	
	1R	2	4	6	
	2R	3	5	8	Average
	3R	6	4	10	9.3
		% Polish		Total % Area Polished	
		T	AT		
Candidate LO268869	1L	15	4	19	
	2L	10	12	22	
	3L	5	2	7	
	1R	5	2	7	
	2R	2	7	9	Average
	3R	4	2	6	11.7
		% Polish		Total % Area Polished	
		T	AT		
Candidate LO271510	1L	10	8	18	
	2L	0	3	3	
	3L	2	4	6	
	1R	16	2	18	
	2R	2	18	20	Average
	3R	1	14	15	13.3
	Percent of total ring travel area				

Table 16 shows the piston skirt surface ratings. Only minor scuffing (<5%) was present on any single piston, which is in line with the ratings seen from the liner surfaces. Remaining defects noted on the piston skirts included only light or trace scratches.

Table 16. DDC 6V53T Piston Skirt Ratings

		Piston Skirt Ratings	
		Thrust	**Anti-Thrust**
MIL-PRF-2104H 15W40	1L	Few Light Scratches, 1% Scuffing	Few Light Scratches, 2% Scuffing
	2L	Few Light Scratches	Few Light Scratches
	3L	Few Light Scratches	Few Light Scratches
	1R	Few Light Scratches	Few Light Scratches
	2R	Few Light Scratches	Few Light Scratches
	3R	Numerous Light Scratches	Few Light Scratches
		Thrust	**Anti-Thrust**
Candidate LO268869	1L	Few Light Scratches & 1% Scuffing	Few Light Scratches
	2L	Few Light Scratches	Few Light Scratches
	3L	Few Light Scratches	Few Very Light Scratches
	1R	Few Light Scratches	Few Light Scratches & 1% Scuffing
	2R	Few Light Scratches	Few Light Scratches & 1% Scuffing
	3R	Few Very Light Scratches	Few Light Scraches & 1% Scuffing
		Thrust	**Anti-Thrust**
Candidate LO271510	1L	5% Light Scratches	Trace Scratches
	2L	Trace Scratches	Trace Scratches
	3L	15% Light Scratches	Trace Scratches
	1R	8% Light Scratches	Trace Scratches
	2R	Trace to Light Scratches	Trace Scratches
	3R	10% Light Scratches	Trace Scratches

As previously mentioned in the GEP 6.5L(T) metrology section, ring mass and radial thickness changes can give insight into the low viscosity oils ability to provide adequate film thickness and protect from excessive ring pack wear. Table 17 and Table 18 show the ring mass and ring radial thickness changes for the 6V53T tests, respectively. From the ring mass measurements, we can again see similar weight loss trends with the low viscosity SCPL candidates compared to the MIL-PRF-2104 15W-40 evaluation as tested during Part 1. Although small, each of the SCPL candidate tests experienced an increased ring pack weight loss compared to the baseline 15W-40 test. Likewise, the same trend is seen with the 1st, 2nd, and 3rd ring radial thickness. Further detailed studies would be required to more definitively quantify the true long term impact of increased wear due to the reduction in oil viscosity. To put this back into military application focus, the correlation initially developed to the 240 hour test was representative of 4,000 miles of

proving ground operation, which does represent a significant life span expectation of tracked vehicles. Due to this consideration, and the overall satisfactory operation and performance of the engine during testing, the revised SCPL candidates do cautiously appear to provide adequate protection.

Table 17. DDC 6V53T Ring Mass Changes, Baseline & SCPL Revised Candidates

Cylinder	Ring No.	MIL-PRF-2104H 15W40	Candidate LO268869	Candidate LO271510
		Delta		
1L	1	0.0145	0.0350	0.0312
	2	0.1140	0.1374	0.0983
	3	0.0601	0.0736	0.0319
	4	0.0169	0.0164	0.0183
	5	0.0241	0.0306	0.0240
2L	1	0.0189	0.0241	0.0313
	2	0.0404	0.0751	0.0571
	3	0.0125	0.0250	0.0193
	4	0.0179	0.0222	0.0137
	5	0.0177	0.0328	0.0189
3L	1	0.0148	0.0345	0.0191
	2	0.0469	0.1102	0.0597
	3	0.0197	0.0385	0.0128
	4	0.0179	0.0187	0.0134
	5	0.0186	0.0280	0.0188
1R	1	0.0111	0.0297	0.0297
	2	0.0717	0.1308	0.1008
	3	0.0328	0.0584	0.0318
	4	0.0202	0.0233	0.0139
	5	0.0208	0.0312	0.0204
2R	1	0.0153	0.0226	0.0177
	2	0.0539	0.0552	0.1104
	3	0.0191	0.0172	0.0544
	4	0.0151	0.0214	0.0162
	5	0.0190	0.0327	0.0407
3R	1	0.0095	0.0321	0.0328
	2	0.0403	0.1072	0.0612
	3	0.0110	0.0641	0.0256
	4	0.0174	0.0201	0.0175
	5	0.0196	0.0463	0.0211

Ring No. 1 max decrease	0.0189	0.0350	0.0328
Ring No. 2 max decrease	0.1140	0.1374	0.1104
Ring No. 3 max decrease	0.0601	0.0736	0.0544
Ring No. 4 max decrease	0.0202	0.0233	0.0183
Ring No. 5 max decrease	0.0241	0.0463	0.0407

Ring No. 1 avg decrease	0.0140	0.0297	0.0270
Ring No. 2 avg decrease	0.0612	0.1026	0.0813
Ring No. 3 avg decrease	0.0259	0.0461	0.0293
Ring No. 4 avg decrease	0.0176	0.0203	0.0155
Ring No. 5 avg decrease	0.0200	0.0336	0.0240

Table 18. DDC 6V53T Top, Second, and Third Ring Radial Thickness, Baseline & SCPL Revised Candidates

MIL-PRF-2104H 15W40				
Radial Thickness		Top Ring	Second Ring	Third Ring
Cylinder	Position	Delta	Delta	Delta
1L	1	0.00080	0.00095	0.00060
	2	0.00020	0.00075	0.00045
	3	0.00035	0.00120	0.00085
	4	0.00005	0.00115	0.00075
	5	0.00075	0.00100	0.00065
2L	1	0.00080	0.00090	0.00025
	2	0.00030	0.00040	0.00020
	3	0.00020	0.00055	0.00015
	4	0.00020	0.00055	0.00015
	5	0.00090	0.00060	0.00040
3L	1	0.00080	0.00075	0.00040
	2	0.00040	0.00035	0.00030
	3	0.00045	0.00070	0.00045
	4	0.00040	0.00040	0.00015
	5	0.00110	0.00065	0.00040
1R	1	0.00125	0.00100	0.00035
	2	0.00000	0.00065	0.00025
	3	0.00035	0.00065	0.00025
	4	0.00035	0.00070	0.00035
	5	0.00160	0.00080	0.00095
2R	1	0.00095	0.00080	0.00030
	2	0.00025	0.00060	0.00030
	3	0.00060	0.00075	0.00030
	4	0.00035	0.00080	0.00030
	5	0.00100	0.00060	0.00035
3R	1	0.00050	0.00050	0.00015
	2	0.00015	0.00060	0.00035
	3	0.00010	0.00255	0.00030
	4	0.00025	0.00035	0.00020
	5	0.00055	0.00050	0.00025
	Maximum	0.00160	0.00255	0.00095
	Average	0.00053	0.00076	0.00037

SCPL Candidate LO268869				
Radial Thickness		Top Ring	Second Ring	Third Ring
Cylinder	Position	Delta	Delta	Delta
1L	1	0.00130	0.00120	0.00075
	2	0.00075	0.00115	0.00070
	3	0.00080	0.00120	0.00080
	4	0.00090	0.00100	0.00050
	5	0.00150	0.00105	0.00070
2L	1	0.00085	0.00070	0.00045
	2	0.00040	0.00075	0.00050
	3	0.00030	0.00085	0.00035
	4	0.00035	0.00070	0.00025
	5	0.00085	0.00080	0.00040
3L	1	0.00135	0.00110	0.00055
	2	0.00060	0.00120	0.00035
	3	0.00035	0.03100	0.00040
	4	0.00045	0.00090	0.00040
	5	0.00140	0.00110	0.00055
1R	1	0.00125	0.00140	0.00085
	2	0.00050	0.00090	0.00030
	3	0.00050	0.00110	0.00050
	4	0.00045	0.00105	0.00060
	5	0.00135	0.00155	0.00140
2R	1	0.00100	0.00060	0.00040
	2	0.00045	0.00065	0.00025
	3	0.00035	0.00080	0.00025
	4	0.00040	0.00055	0.00025
	5	0.00065	0.00070	0.00035
3R	1	0.00150	0.00100	0.00065
	2	0.00085	0.00075	0.00050
	3	0.00065	0.00110	0.00065
	4	0.00085	0.00100	0.00090
	5	0.00040	0.00120	0.00095
	Maximum	0.00150	0.03100	0.00140
	Average	0.00078	0.00197	0.00055

SCPL Candidate LO271510				
Radial Thickness		Top Ring	Second Ring	Third Ring
Cylinder	Position	Delta	Delta	Delta
1L	1	0.00090	0.00085	0.00045
	2	0.00030	0.00070	0.00045
	3	0.00005	0.00095	0.00050
	4	0.00050	0.00085	0.00040
	5	0.00120	0.00145	0.00070
2L	1	0.00065	0.00065	0.00035
	2	0.00060	0.00090	0.00035
	3	0.00045	0.00065	0.00050
	4	0.00010	0.00065	0.00020
	5	0.00065	0.00060	0.00050
3L	1	0.00065	0.00050	0.00025
	2	0.00015	0.00080	0.00025
	3	0.00035	0.00070	0.00035
	4	0.00015	0.00070	0.00015
	5	0.00065	0.00075	0.00025
1R	1	0.00115	0.00080	0.00055
	2	0.00020	0.00075	0.00020
	3	0.00075	0.00145	0.00025
	4	0.00040	0.00095	0.00045
	5	0.00120	0.00060	0.00050
2R	1	0.00120	0.00095	0.00085
	2	0.00050	0.00085	0.00055
	3	0.00030	0.00135	0.00050
	4	0.00055	0.00065	0.00050
	5	0.00150	0.00100	0.00070
3R	1	0.00060	0.00065	0.00030
	2	0.00010	0.00060	0.00025
	3	0.00005	0.00075	0.00085
	4	0.00045	0.00055	0.00040
	5	0.00095	0.00050	0.00040
	Maximum	0.00150	0.00145	0.00085
	Average	0.00058	0.00080	0.00043

Table 19 shows the slipper bushing weight loss for each of the DDC 6V53T tests. The baseline MIL-PRF-2104H 15W-40 test experienced an average slipper bushing weight loss of 0.11 grams compared to the revised SCPL candidates average of 0.15 grams. This change in weight loss was not immediately alarming, and was reinforced by the slipper bushing visual ratings reported in Table 20.

Table 19. DDC 6V53T Slipper Bushing Mass Changes, Baseline & SCPL Revised Candidates

	Slipper Bushing	Before	After	Change
MIL-PRF-2104H 15W40	1L	56.2768	56.2085	0.0683
	2L	55.9443	55.8420	0.1023
	3L	56.2014	56.0414	0.1600
	1R	56.0874	56.0086	0.0788
	2R	56.2125	56.1151	0.0974
	3R	56.1273	55.9975	0.1298

Maximum	0.1600
Average	0.1061

	Slipper Bushing	Before	After	Change
Candidate LO268869	1L	56.1310	55.9758	0.1552
	2L	56.0567	55.9313	0.1254
	3L	56.0873	55.9811	0.1062
	1R	56.0515	55.8908	0.1607
	2R	56.0870	55.9288	0.1582
	3R	55.7503	55.5740	0.1763

Maximum	0.1763
Average	0.1470

	Slipper Bushing	Before	After	Change
Candidate LO271510	1L	56.1116	55.9466	0.1650
	2L	56.3117	56.1454	0.1663
	3L	56.0924	55.9997	0.0927
	1R	56.0745	55.9075	0.1670
	2R	55.9797	55.7885	0.1912
	3R	56.4089	56.2706	0.1383

Maximum	0.1912
Average	0.1534

Table 20 shows the slipper bushing exposed copper ratings. The two revised candidate SCPL tests yielded reduced exposed copper than the baseline 15W-40 test. This again demonstrates that the revised SCPL candidates are providing adequate engine protection. None of the slipper bushings experienced wear that would be considered detrimental to performance. This is noted in the metrology and ratings, as well as a lack of bearing related wear metal accumulation in the used oil.

Table 20. DDC 6V53T Slipper Bushing Exposed Copper Ratings

Slipper Bushing % Exposed Copper	MIL-PRF-2104H 15W-40	Candidate LO268869	Candidate LO271510
1L	2	1	0
2L	15	1	10
3L	10	2	0
1R	6	2	12
2R	8	1	15
3R	12	2	2
Average	8.83	1.50	6.50

Table 21 shows the connecting rod bearing weight loss for each DDC 6V53T test. Like the slipper bushings, a similar trend was also seen here. The revised candidate SCPL evaluations yielded a higher average weight loss than the baseline, with measured averages of 0.014 and 0.011 grams for the revised SCPL candidates, and 0.009 grams for the 15W-40 baseline. As before, this increase was not an alarming result. All of the removed connecting rod bearings appeared to be in good condition upon visual inspection, and low levels of lead and copper wear metals in the engines used oil analysis suggest low overall bearing distress.

Table 21. DDC 6V53T Connecting Rod Bearing Mass Changes, Baseline & SCPL Revised Candidates

Oil	Rod Bearing	Shell	Before	After	Change
MIL-PRF-2104H 15W40	1L	Top	73.6495	73.6297	0.0198
		Bottom	67.8243	67.8210	0.0033
	2L	Top	73.4362	73.4133	0.0229
		Bottom	67.7831	67.7786	0.0045
	3L	Top	73.4769	73.4644	0.0125
		Bottom	67.8587	67.8555	0.0032
	1R	Top	73.4915	73.4771	0.0144
		Bottom	68.3085	68.3036	0.0049
	2R	Top	73.4822	73.4681	0.0141
		Bottom	68.1717	68.1779	-0 0062
	3R	Top	73.2623	73.2486	0.0137
		Bottom	69.3699	69.3658	0.0041

Maximum	0 0229
Average	0 0093

Oil	Rod	Shell	Before	After	Change
SCPL Candidate LO268869	1L	Top	73.5096	73.4845	0.0251
		Bottom	68.4050	68.3979	0.0071
	2L	Top	73.5891	73.5602	0.0289
		Bottom	67.9048	67.9006	0.0042
	3L	Top	73.5592	73.5377	0.0215
		Bottom	68.0659	68.0599	0.0060
	1R	Top	73.7570	73.7359	0.0211
		Bottom	67.8936	67.8878	0.0058
	2R	Top	73.5076	73.4869	0.0207
		Bottom	67.9593	67.9563	0.0030
	3R	Top	73.4451	73.4258	0.0193
		Bottom	67.8821	67.8766	0.0055

Maximum	0 0289
Average	0 0140

Oil	Rod Bearing	Shell	Before	After	Change
SCPL Candidate LO271510	1L	Top	73.5154	73.4940	0.0214
		Bottom	69.0551	69.0506	0.0045
	2L	Top	73.5056	73.4842	0.0214
		Bottom	68.8418	68.8369	0.0049
	3L	Top	73.6489	73.6331	0.0158
		Bottom	69.0457	69.0425	0.0032
	1R	Top	73.3940	73.3765	0.0175
		Bottom	67.8570	67.8504	0.0066
	2R	Top	73.7199	73.7059	0.0140
		Bottom	68.4373	68.4338	0.0035
	3R	Top	73.7069	73.6937	0.0132
		Bottom	68.1779	68.1725	0.0054

Maximum	0.0214
Average	0 0109

In addition to the metrology, deposit ratings were completed on post test pistons, rings, and liners to assess the ability of each oil to control deposit formation and buildup. Table 22 shows the overall piston deposits accumulated for each test. The two revised candidates had similar overall deposit levels compared to the baseline 15W-40 test. As with the 6.5L(T), none of the deposit levels shown were considered excessive.

Table 22. DDC 6V53T Post-Test Piston Deposit Ratings

	MIL-PRF-2104H 15W40	Candidate LO268869	Candidate LO271510
Piston Carbon, Average Demerits			
No.1 Groove	60.33	62.58	58.96
No.2 Groove	34.54	35.13	37.00
No.3 Groove	24.46	23.25	22.79
No.1 Land	40.25	40.50	41.71
No.2 Land	57.08	59.88	56.50
No.3 Land	10.58	16.79	10.00
No.4 Land	6.88	6.42	3.54
Piston Lacquer, Average Demerits			
No.1 Groove	0.00	0.00	0.00
No.2 Groove	0.01	0.00	0.00
No.3 Groove	0.08	0.31	0.23
No.1 Land	0.26	0.00	0.00
No.2 Land	0.09	0.00	0.00
No.3 Land	1.93	1.52	1.78
No.4 Land	2.50	2.57	2.64
Total, Average Demerits	238.99	248.94	235.16

Miscellanous (Average)			
Top Groove Fill, %	59.50	62.00	73.00
Intermediate Groove Fill, %	60.50	58.83	66.50
Top Land Heavy Carbon, %	21.33	20.67	22.83
Top Lan Flaked Carbon, %	0.00	0.17	0.00

Table 23 shows deposit ratings for the ring packs only. Interestingly, all of the tests show some propensity to develop deposits on the 2nd fire ring. This resulted in a varying amount of cold stuck rings for the post test pistons. From the ratings, it was found that the two revised SCPL candidates showed better overall control of deposit formations resulting in fewer stuck rings. The baseline 15W-40 test showed 5 of the 6 number 2 rings to be cold stuck, varying between 10 to 95% of the ring circumference being unmovable. The two revised candidate SCPL tests only showed two cold stuck rings each, with much lower pinched ring circumferences. Specific carbon ratings of the number two rings were performed to better quantify this carbonaceous accumulation, and the baseline 15W-40 showed nearly twice the heavy carbon buildup as revised

candidate LO268869. Unfortunately, the second rings for revised candidate LO271510 were inadvertently cleaned (i.e., carbon removed via abrasive blasting) for metrology measurements prior to the ratings being completed, but based solely off of the ring sticking ratings, it would have likely shown similar rating trends as LO268869.

Table 23. DDC 6V53T Ring Pack Ratings

Oil	Ratings	1L	2L	3L	1R	2R	3R	Average
	Ring Pack Deposit Control — Cylinder Number							
MIL-PRF-2104H 15W40	**Ring Sticking** (F=Free, CS=Cold Stuck, HS=Hot Stuck, CP=Collapsed Ring, No. Denotes % Of Ring Circumference)							
	Top	F	F	F	F	F	F	
	Second	25% CS	F	40% CS	10% CS	95% CS	90% CS	
	Third	F	F	F	F	F	F	
	Oil Control Rings	F	F	F	F	F	F	
	2nd Ring Carbon							**Average**
	Heavy Carbon	26	33	93	70	76	53	59
	Light Carbon	74	67	7	30	20	37	39
Candidate LO268869	**Ring Sticking**							
	Top	F	F	F	F	F	F	
	Second	F	CS 5%	CS 10%	F	F	F	
	Third	F	F	F	F	F	F	
	Oil Control Rings	F	F	F	F	F	F	
	2nd Ring Carbon							**Average**
	Heavy Carbon	62	10	78	5	4	40	33
	Light Carbon	38	90	22	46	86	60	57
Candidate LO271510	**Ring Sticking**							
	Top	F	F	F	F	F	F	
	Second	F	F	F	F	CS 20%	CS 15%	
	Third	F	F	F	F	F	F	
	Oil Control Rings	F	F	F	F	F	F	
	2nd Ring Carbon							**Average**
	Heavy Carbon	-	-	-	-	-	-	-
	Light Carbon	-	-	-	-	-	-	-

Lastly, intake port plugging for each liner was quantified as another form of determining deposit control. Similar to what was seen in the ring pack ratings, the two revised candidates showed less overall intake port buildup than the baseline 15W-40. All of the intake port deposits were considered minor. Intake port deposit levels can be seen in Table 24.

Full DDC 6V53T test report data from each revised candidate test (LO268869 and LO271510) are presented in Appendix B1, and B2 respectively.

Table 24. DDC 6V53T Intake Port Plugging

Intake Port Plugging	MIL-PRF-2104H 15W40	Canddiate LO268869	Candidate LO271510
1L	2.5	2	3
2L	2	2	3
3L	3	3	2
1R	0.5	3	2
2R	1	2	2
3R	25.5	3	2
Average	5.75	2.5	2.33

3.4 6.5L Roller Follower Wear Testing

Each revised SCPL candidate was also evaluated in the ASTM D5966 Roller Follower Wear Test. This procedure, approved for API CJ-4 oil qualification, is used to determine the effects of lubricating oil on camshaft roller follower axle wear. The engine used in testing is the GM 6.5L(NA) V8 diesel engine, which is the base engine the GEP family of V8 diesel engines originate from. The test operates the engine near maximum load at 1000 rpm for a total of 50 hours while controlling engine coolant out and oil galley temperatures at 248 °F. The test is completed without an oil change, with makeup oil being added at the 25 hour point. Once completed, the roller follower assemblies are removed from the engine and disassembled, and the roller axles are measured using a single pass profilometer to determine resulting axle wear. Table 25 on the following page shows the results for the two revised candidates, and the single test MTAC limits set out by the API CJ-4 classification. From the results, we can see that the average axle wear for both revised candidates remains under the maximum average of 0.30 mils allowed by the CJ-4 classification. Revised candidate LO268869 had the higher wear, and resulted just under the MTAC limit at 0.28 mils, while LO271510 had an average wear of 0.15 mils. When comparing the maximum and minimum measurements for all of the follower assemblies, it becomes more clear how variable the wear can be in a single test. The MTAC limits increase to 0.33 mils for a two test qualification, and 0.36 mils for a three test qualification. Both revised candidates passed the CJ-4 requirements, and demonstrate adequate protection of the roller follower assembly.

Full ASTM test reports for each revised candidate can be reviewed in Appendix C1 and C2 for revised candidates LO268869 and LO271510 respectively.

Table 25. ASTM D5966 Roller Follower Wear Results

	Single Test CJ-4 MTAC Limits	SCPL LO268869	SCPL LO271510
Follow Axle Wear, Average [mil]	0.30	0.28	0.15
Maximum	N/A	0.47	0.31
Minimum	N/A	0.12	0.07

3.5 TRANSMISSION COMPATIBILITY

As stated in the background and introduction, the SCPL must be capable of being used in military power shift transmission applications in addition to engine crankcase applications. To assess the transmission performance of each revised SCPL candidate, several industry standardized transmission test procedures were completed, including selected: Allison C4, Caterpillar TO-4, and John Deere JDQ test procedures. Many of these industry transmission frictional tests utilize an SAE No. 2 friction testing machine. This machine measures the engagement properties of one friction and reaction plate over a wide range of speeds and application forces. It instantaneously records multiple parameters including load applied, torque transmitted, and plate speed to determine overall torque capacity, dynamic and static coefficients of friction, and slip time. Results are then compared to a baseline fluid which brackets desired performance and determines pass fail of a candidate fluid. Results for the SCPL testing are summarized as follows.

3.5.1 Allison C4 Testing

Allison C4 transmission compatibility evaluations for the revised SCPL candidate included frictional testing using paper and graphite materials. Table 26 shows the results from the paper friction testing. Overall, neither of the revised candidates changed their pass/fail results with respect to their initial evaluations. Like initial candidate LO253071, revised candidate LO268869 fell short on the minimum midpoint coefficient of friction at the 100 cycles engagement. This could potentially manifest itself as a greater amount of slip of the friction material during early engagements. Revised candidate LO271510 again passed the paper friction testing.

Table 26. Revised SCPL Candidate Evaluations, Allison C4 Paper Friction

Initial Candidates

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO-253071**	Test Number:	**C2-7-1552**
Lab Fluid Code:	**253071**	Fric. Plate Batch:	**Batch 5**
Completion Date:	**07/25/2010**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0 600	N/A	0.540	0.450	-16.67	**P**
Mid-Point Fric. Coeff. Min.	0 096	N/A	0.087	0.114	31 03	**F**
Static Friction Coeff.	N/A	N/A	0.161	0.125	-22.36	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.173	0.135	-21.97	
0 25 Second Low Speed Coeff.	N/A	N/A	0.163	0.131	-19.63	

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO-251746**	Test Number:	**C2-6-1551**
Lab Fluid Code:	**251746**	Fric. Plate Batch:	**BATCH 5**
Completion Date:	**07/23/2010**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0 600	N/A	0.470	0.420	-10.64	**P**
Mid-Point Fric. Coeff. Min.	0 096	N/A	0.103	0.120	16 50	**P**
Static Friction Coeff.	N/A	N/A	0.173	0.160	-7 51	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.197	0.173	-12.18	
0 25 Second Low Speed Coeff.	N/A	N/A	0.182	0.165	-9 34	

Revised Candidates

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO268869**	Test Number:	**C2-3-1573**
Lab Fluid Code:	**268869**	Fric. Plate Batch:	**Lot 6**
Completion Date:	**10/15/2011**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0 600	N/A	0.530	0.460	-13.21	**P**
Mid-Point Fric. Coeff. Min.	0 096	N/A	0.093	0.111	19 35	**F**
Static Friction Coeff.	N/A	N/A	0.103	0.111	7.77	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.102	0.115	12.75	
0 25 Second Low Speed Coeff.	N/A	N/A	0.095	0.111	16 84	

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO271510**	Test Number:	**C2-4-1574**
Lab Fluid Code:	**271510**	Fric. Plate Batch:	**Lot 6**
Completion Date:	**10/17/2011**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0 600	N/A	0.500	0.430	-14.00	**P**
Mid-Point Fric. Coeff. Min.	0.085	N/A	0.095	0.118	23.16	**P**
Static Friction Coeff.	N/A	N/A	0.173	0.158	-8 67	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.187	0.166	-11.23	
0 25 Second Low Speed Coeff.	N/A	N/A	0.171	0.163	-9 94	

Table 27 shows the results from the graphite friction testing. Both initial candidates LO253071 and LO251746 did not meet the targets in either slip time or midpoint minimum coefficient of friction. Both candidates performed similarly overall. Each showed a borderline increase in slip time with respect to the maximum allowable for the 5,500 cycles engagement (1,500 cycles engagement OK). For midpoint friction coefficient, each candidate met the minimum at 1,500 cycles engagement but fell below the specification at 5,500 cycles engagement. For revised candidate LO268869, the formulations changes improved the slip time response staying below the maximum allowable time. LO268869 was still below the minimum midpoint coefficient of friction, but would be considered a borderline fail (0.088 versus passing 0.089). Revised candidate LO271510's formulation changes allowed a passing result for both criteria.

Full Allison C4 frictional test report data from each revised candidate test, LO268869, and LO271510 are presented in Appendix D1, and D2 respectively.

Table 27. Revised SCPL Candidate Evaluations, Allison C4 Graphite Friction Testing

Initial Candidates

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO253071** Test Number: **C4-8-1286**
Lab Fluid Code: **LO-253071** Fric. Plate Batch: **BATCH 44**
Completion Date: **7/22/2010** Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.79	0.91	15.19	F
0.2 Second Dynamic Coeff.	N/A	N/A	0.084	0.063	-25.000	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.093	0.082	-11.828	F
Static Friction Coeff.	N/A	N/A	0.129	0.112	-13.178	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.154	0.136	-11.688	
0.25 Second Low Speed Coeff.	N/A	N/A	0.130	0.123	-5.385	

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO251746** Test Number: **C4-7-1285**
Lab Fluid Code: **LO-251746** Fric. Plate Batch: **Batch 44**
Completion Date: **7/21/2010** Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.81	0.90	11.11	F
0.2 Second Dynamic Coeff.	N/A	N/A	0.072	0.048	-33.333	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.090	0.084	-6.667	F
Static Friction Coeff.	N/A	N/A	0.142	0.136	-4.225	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.160	0.153	-4.375	
0.25 Second Low Speed Coeff.	N/A	N/A	0.149	0.142	-4.698	

Revised Candidates

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO268869** Test Number: **C4-3-1341**
Lab Fluid Code: **268869** Fric. Plate Batch: **Lot 44**
Completion Date: **10/14/2011** Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.75	0.86	14.67	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.090	0.067	-25.556	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.099	0.087	-12.121	BL-F
Static Friction Coeff.	N/A	N/A	0.132	0.113	-14.394	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.138	0.123	-10.870	
0.25 Second Low Speed Coeff.	N/A	N/A	0.126	0.112	-11.111	

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO271510** Test Number: **C4-4-1342**
Lab Fluid Code: **271510** Fric. Plate Batch: **Lot 44**
Completion Date: **10/15/2011** Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.76	0.81	6.58	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.086	0.077	-10.465	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.097	0.094	-3.093	P
Static Friction Coeff.	N/A	N/A	0.140	0.128	-8.571	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.164	0.148	-9.756	
0.25 Second Low Speed Coeff.	N/A	N/A	0.147	0.140	-4.762	

3.5.2 Caterpillar TO-4 Testing

Similar to the Allison C4 transmission compatibility tests, Caterpillar TO-4 standardized tests were completed on each revised candidate to assess potential performance in Caterpillar transmission applications. The Caterpillar TO-4 testing matrix for the SCPL candidates included frictional testing on sintered bronze (Sequence 1220) and wheel brake paper (Sequence 1222).

Table 28 shows a summary of the CAT TO-4 frictional testing. Revised candidate LO268869 showed essentially no change over its initial evaluation (LO253071) by passing the sintered bronze (SEQ1220) and failing the wheel brake paper (SEQ1222) tests. For revised candidate LO271510, the formulation changes improved the sintered bronze (SEQ1220) response and passed the test, but still failed the wheel brake paper (SEQ1222).

Both revised SCPL candidates continue to struggle with the wheel brake paper (SEQ1222) portion of the CAT TO-4 test. From further review, revised candidate LO268869 generally showed lower coefficients of friction (static and dynamic) than the limit lines generated by reference fluids. This would suggest increased slipping and potentially reduced torque capacity in a wet clutch/brake arrangement. Despite this, the coefficient of friction traces remained smooth and predictable throughout testing, not showing any tendencies to rapidly change its frictional properties. This suggests that, although a technical failure, the candidate should not cause catastrophic failure within a transmission, but has room for improvement to ensure proper performance in all scenarios. Upon further review of revised candidate LO271510's wheel brake paper (SEQ1222) results, failures only occurred during the dynamic coefficient friction tests. In general it showed very borderline failures during each of these traces with only 1 to 2 points being below the limit lines of the reference fluid. Figure 6 on the following page shows a plot of one of the borderline dynamic coefficient failures seen during LO271510 testing. This suggest that again, although a technical failure, the candidate should perform as intended in this type application.

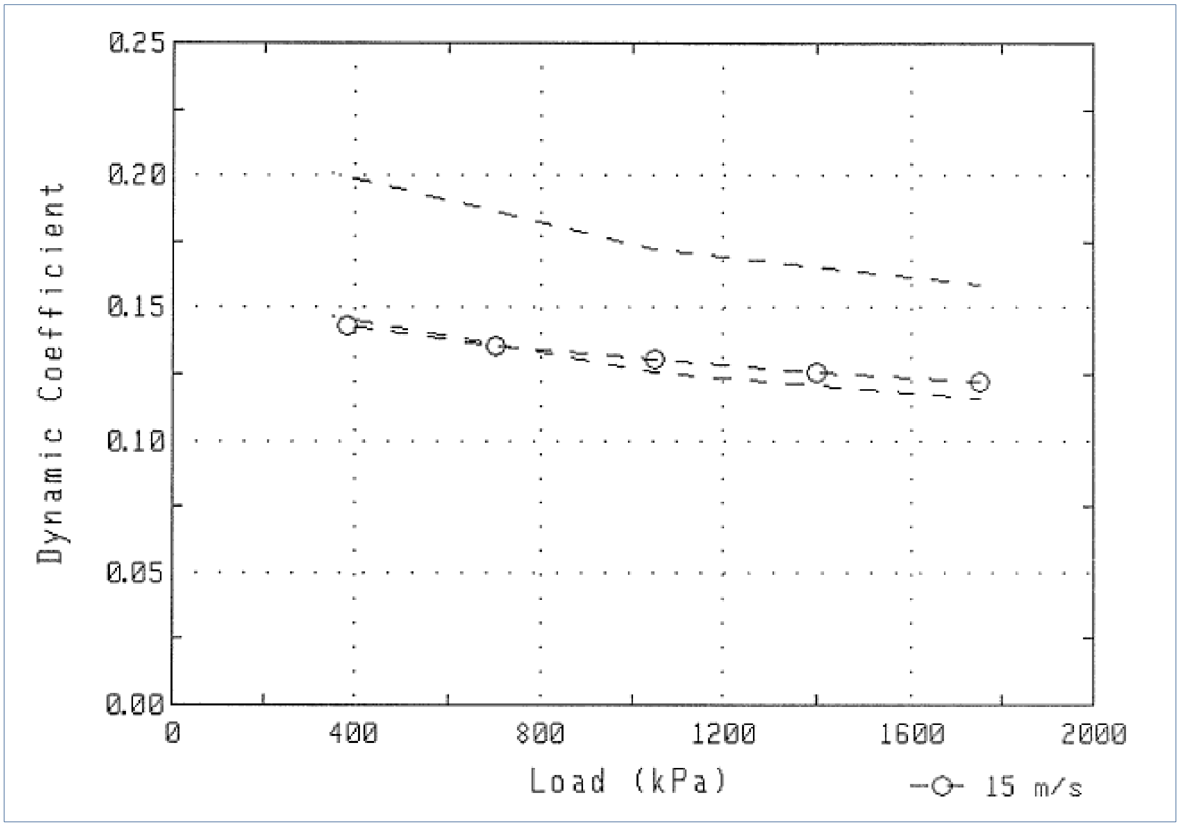

Figure 6. Revised SCPL Candidate LO271510, CAT TO-4 SEQ1222 Dynamic Coefficient of Friction vs Load Trace

As before, it is expected that all of these borderline failures for the revised SCPL candidates could be corrected with slight formulation changes. None of the SCPL candidates exhibited behaviors that would be considered catastrophic if used in transmissions, but room for improvement remains for the SCPL oils in regards to Caterpillar TO-4 friction testing. Full Caterpillar TO-4 test report data from each candidate test, LO268869 and LO271510, are presented in Appendix E1, and E2 respectively.

Table 28. Revised SCPL Candidate Evaluations, Caterpillar TO-4 Friction Testing

CAT TO-4	LO253071	LO268869	LO251746	LO271510
Sequence 1220	*initial*	*revised*	*initial*	*revised*
Dynamic Coef vs Cycle	Pass	Pass	Fail	Pass
Dynamic Coef vs Load	Pass	Pass	Fail	Pass
Dynamic Coef vs Speed	Pass	Pass	Fail	Pass
Energy Limit	Pass	Pass	Pass	Pass
Static Coef vs Load	Pass	Pass	Fail	Pass
Static Coef vs Speed	Pass	Pass	Fail	Pass
Energy Limit	Pass	Pass	Pass	Pass
Total Wear	0.039	0.016	0.039	0.006
Sequence 1222				
Dynamic Coef vs Cycle	Fail	Fail	Fail	Fail
Dynamic Coef vs Load	Fail	Fail	Fail	Fail
Dynamic Coef vs Speed	Fail	Fail	Fail	Fail
Energy Limit	Pass	Pass	Pass	Pass
Static Coef vs Load	Fail	Fail	Fail	FP
Static Coef vs Speed	Pass	Fail	Fail	Pass
Energy Limit	Pass	Pass	Pass	Pass
Total Wear	0.03	0.029	0.007	0.029
Friction Retention				
	Pass	N/A	Pass	N/A

3.5.3 John Deere JDQ-96 Wet Brake Testing

John Deere JDQ-96 testing assesses lubricant interactions with a submerged wet braking system. Although not a MIL-PRF-2104 spec requirement, this test provides useful information into the frictional properties of the candidate SCPLs combined with different friction materials. As with previous evaluations, an abbreviated 1,000 cycle test was run to get an indication of overall compatibility for the revised SCPL candidates. The two main primary parameters of interest are the relative capacity, and overall torque variation. The relative capacity is a measure of the overall torque capacity of the system with the lubricant being tested, and torque variation is a measure between the peak and valley of the torque trace calculated from high speed torque data acquired across several engagements.

It is important to note here, that direct comparisons between initial and revised candidate testing cannot be made. This is due to a change in the John Deere JDQ-96 test stand. Previously the stand was motored using a fired diesel engine to operate the test axle, whereas the new stand uses a large variable speed drive for powering. This has caused some shifting in results generated between the two stand configurations. In addition, it has been noted by project managers that the JDQ-96 test is sensitive to the actual braking hardware being used. Even from hardware supplied from a single source, the magnitude of torque variation has been found to be highly hardware dependant. To help mitigate these confounding effects, a 1,000 cycle reference was operated using the tested components (piston & backing plate) prior to running the candidate tests, so that baseline data was most relevant to the results.

Table 29 summarizes results for each of the revised SCPL candidates and their respective initial evaluations. All of the candidates provided adequate torque capacity compared to the reference fluid baseline. The overall torque variation for the revised SCPL candidates was again larger than that of the reference fluid, a trend that was consistent with initial SCPL evaluations. This behavior has been noted in previous testing as being typical of engine oils in this type application. This explains each fluid being noted as creating high levels of brake noise. Other than a higher level of audible noise, this increase should not pose adverse effects on overall function and usability of the system.

Full JDQ-96 test report data from each candidate test, LO268869, and LO271510 are presented in Appendix F1 and F2 respectively.

Table 29. SCPL Revised Candidate Evaluations, JDQ-96 Wet Brake Compatibility

John Deere JDQ-96				
Performed using 1400 Series Axle	***initial***	***initial***	***revised***	***revised***
Test Number	10979	10739	11843	111114
Oil Code	**LO253071**	**LO251746**	**LO268869**	**LO271510**
EOT Date	8/2/2010	7/31/2010	11/23/2011	12/1/2011
Relative Capacity	**Current Reference Baseline Average (N*m)**			
@ 1,000 Cycles	342,372	342,372	330,753	330,753
Torque Variation				
@ 1,000 Cycles	93,746	93,746	171,228	171,228
Relative Capacity	**Results From Test Candidate**			
@ 1,000 Cycles	360,738	398,534	335,125	392,229
Torque Variation				
@ 1,000 Cycles	164,190	253,990	206,202	264,603
**Notes	This oil created high levels of brake noise.	This oil created high levels of brake noise.	This oil created high levels of brake noise.	This oil created high levels of brake noise.

3.6 ENGINE FUEL CONSUMPTION IMPROVEMENT

To quantify fuel consumption improvements from the use of SCPL candidates, it was desired to develop a “standardized” type test to measure the fuel consumption of a baseline oil compared to each SCPL candidate. The following sections summarize the test stand configuration, cycle development, and procedures used during fuel consumption testing. Results are presented for the revised SCPL candidate evaluations.

3.6.1 Stand Configuration and Cycle Development

Similar to Part 1, fuel consumption evaluations were conducted on a test stand configured for the GEP 6.5L(T) engine, similar in many ways to the stand used for endurance evaluations. Variations between the two stands included oil system heat exchanger layout and the inclusion of an inlet air cooler for finer intake air temperature control. Field data from actual HMMWV operation at Ft. Hood, TX was used to create a series of 26 operating modes for testing. After determining which modes had the highest repeatability when conducted in the laboratory setting, a 14-mode cycle was derived. Power output and fuel flow rate (measured by a coriolis mass-flow meter) were used to calculate the engine break-specific fuel consumption (BSFC) for each of the 14 operating modes. After completing all 14 modes, each mode’s BSFC value was weighted

based upon the corresponding fuel flow rate and then combined to form a cycle BSFC result. For each lubricant evaluation, the 14-mode cycle was repeated seven times for repeatability purposes to verify BSFC changes.

3.6.2 Fuel Consumption Test Procedure

Prior to testing each candidate oil, a baseline SAE 40 oil was run to measure and account for engine drift over time. Engine oil was changed in the engine using a double flush method, along with an accompanying filter change. Once fluid levels were set, the engine was started and idled for 60 seconds to stabilize operation and check for system leaks. Next, a 1,500 rpm, half throttle warm-up brought up engine coolant and oil temperatures prior to test cycle initiation. Throughout testing, inlet air was maintained at 75 °F, and fuel temperature at 95 °F. The fuel source used for the evaluations was identical to that used in SCPL endurance testing in the GEP 6.5L(T) engine (Appendix G). Following warm-up, the engine was brought to rated conditions (full load, 3,400 rpm) to set inlet and exhaust restrictions (0.55 psi and 0.27 psi respectively). After the restrictions were set and verified, the engine was then ramped down and controlled to 1,100 rpm and 60 lb-ft for 30 minutes to stabilize temperatures before continuing with the 14-mode cycle shown in Table 30.

Table 30. GEP 6.5L(T) Fuel Consumption Test Points

Point	RPM	Torque, lb-ft	Power, hp	Oil Sump, ˚F	Intake Air, ˚F	Fuel Inlet, ˚F
1	1100	59.7	12.5	165	75	95
2	2100	59.7	23.9	180		
3	1100	99.6	20.9			
4	1100	179.2	37.5			
5	1600	99.6	30.3	195		
6	2100	139.4	55.7			
7	2600	99.6	49.3	215		
8	2100	179.2	71.7			
9	3100	99.6	58.8			
10	2600	139.4	69.0			
11	3100	139.4	82.3	245		
12	2600	179.2	88.7			
13	2400	302.4	138.2			
14	2800	250.8	133.7			

At the completion of mode 14, the engine would return to the 30 minute stabilization step for the next cycle. This continued until all seven cycles were completed. In the event of a shut-down, the cycle was restarted from the temperature stabilization step.

3.6.3 Candidate Results

Results from the revised candidate SCPL's are shown in Table 31 and Table 32. The (4) and (5) associated with the SAE 40 Baseline results reference the order in which that baseline evaluation occurred for the engine installation. Additional baseline evaluations were conducted prior to the SCPL candidate evaluations to ensure engine stability and oil discrimination.

Table 31. LO271510 Fuel Consumption Improvement

General Engine Products 6.5 Turbo Fuel Consumption		**BSFC**
	Run	**FE Cycle**
SAE 40 LO258269 Baseline (4)	1	0.4989
	2	0.4997
	3	0.4988
	4	0.4983
	5	0.4961
	6	0.4932
	7	0.4968
	Average	0.49741
	Standard Deviation	0.00224
	COV	0.45%
Revised SCPL LO271510 Candidate	1	0.4854
	2	0.4856
	3	0.4830
	4	0.4848
	5	0.4860
	6	0.4845
	7	0.4836
	Average	0.48472
	Standard Deviation	0.00109
	COV	0.22%
	Percent change:	**2.55%**
	F-Test, two tail	0.102
	Variance: Equal=2, Unequal=3	2
	T-test	1.29×10^{-08}
	Statistically significant with 95% CI	Yes
	Statistically significant with 99% CI	Yes

Table 32. LO268869 Fuel Consumption Improvement

General Engine Products 6.5 Turbo Fuel Consumption		**BSFC**
	Run	**FE Cycle**
SAE 40 LO258269 Baseline (5)	1	0.4980
	2	0.4977
	3	0.4974
	4	0.4983
	5	0.4961
	6	0.4969
	7	0.4988
	Average	0.49760
	Standard Deviation	0.00090
	COV	0.18%
Revised SCPL LO268869 Candidate	1	0.4874
	2	0.4861
	3	0.4857
	4	0.4845
	5	0.4835
	6	0.4842
	7	0.4830
	Average	0.48490
	Standard Deviation	0.00157
	COV	0.32%
	Percent change:	**2.55%**
	F-Test, two tail	0.205
	Variance: Equal=2, Unequal=3	2
	T-test	3.33×10^{-10}
	Statistically significant with 95% CI	Yes
	Statistically significant with 99% CI	Yes

Both revised SCPL candidate lubricants showed a statistically significant improvement of 2.55% with respect to the SAE 40 baseline oil. To determine the shift in engine baseline performance, the baseline tests used in each of the candidate lubricant evaluations were compared. This is shown in Table 33.

Table 33. SAE 40 Baseline Shift

General Engine Products 6.5 Turbo Fuel Consumption		**BSFC**
	Run	**FE Cycle**
SAE 40 LO258269 Baseline (4)	1	0.4989
	2	0.4997
	3	0.4988
	4	0.4983
	5	0.4961
	6	0.4932
	7	0.4968
	Average	0.49741
	Standard Deviation	0.00224
	COV	0.45%
SAE 40 LO258269 Baseline (5)	1	0.4980
	2	0.4977
	3	0.4974
	4	0.4983
	5	0.4961
	6	0.4969
	7	0.4988
	Average	0.49760
	Standard Deviation	0.00090
	COV	0.18%
	Percent change:	**-0.04%**
	F-Test, two tail	0.044
	Variance: Equal=2, Unequal=3	3
	T-test	8.44×10^{-01}
	Statistically significant with 95% CI	No
	Statistically significant with 99% CI	No

4.0 CONCLUSIONS

From testing completed, the revised SCPL candidates provided promising results for the continued development of the SCPL. Overall engine durability and oil degradation testing using the GEP 6.5L(T) engine yielded improved results. Revised candidate LO268869 showed the most improvement in the GEP 6.5L(T) testing, and was capable of operating to the full 210 hour test target while maintaining acceptable used oil condition. Although revised candidate LO271510 did not make the target 210 hours, it ran for 196 hours prior to termination, which is an improvement over its initial evaluation. Both revised candidates demonstrated improved oxidation stability over current military approved oils as tested during Part 1, which reinforces the feasibility aspects of SCPL utilization. In the 2-cycle diesel engine testing using the DDC 6V53T, both revised candidates provided comparable, and in some cases such as deposit control, better performance than that seen during the MIL-PRF-2104H OE/HDO 15W-40 baseline. This suggests that low viscosity SCPL can be successfully used in the military's 2-cycle engines. Lastly, the ASTM D5966 Roller Follower Wear Test demonstrated that each revised candidate provided adequate protection to critical roller follower valve train components.

Transmission testing completed on the revised candidates again confirmed the possibilities of using the SCPL in powershift transmission applications. Some improvements were made over the initial SCPL candidates provided, but further modifications in formulation are desired to improve function and ensure adequate performance during all conditions. Despite this, none of the revised SCPL candidates exhibited any catastrophic incompatibility with typical transmission components they would be expected to come into contact with.

Lastly, fuel consumption improvements were found to be similar for both revised candidate lubricants. Results help confirm that through the use of low viscosity lubricants, potential fuel savings for the military could be realized. The 2.55% improvement over the SAE40 baseline oil translates into an approximate 1.5% improvement over MIL-PRF-2104H 15W-40 diesel engine oils [4]. These savings, combined with goals of extended drain intervals, all help in making an SCPL lubricant potentially cost effective when compared to current products.

5.0 RECOMMENDATIONS

It is the recommendation of TFLRF staff that both LO268869 and LO271510 continue to be considered candidates for the SCPL program. Formulation changes need to be made for both candidates to improve transmission performance without negatively impacting engine durability, oil degradation, and 2-cycle compatibility.

Long term considerations for the SCPL program should include:

- High temperature 2–cycle diesel engine compatibility testing
- Aircooled diesel engine compatibility using the AVDS-1790 engine
- Detailed investigation of ring pack wear changes due to lowered viscosities
- Conduct multiple field demonstrations at U.S. Army posts consisting of cold, moderate, and high temperature climate conditions.

6.0 REFERENCES

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2. Warden, R.W, et. al. *"Fuel Efficiency Effects of Lubricants in Military Vehicles,"* SAE Technical Paper 2010-01-280, 2010.
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4. Brandt, A.C., Frame, E.A., Hansen, G.A., Warden, R.W., *"Single Common Powertrain Lubricant Development,"* Draft Interim Report TFLRF No. 418, January 2012.
5. Brandt, A.C., Frame, E.A., Alvarez, R.A., *"Feasibility of using Full Synthetic Low Viscosity Engine Oil at High Ambient Temperatures in U.S. Army Engines"*, Interim Report TFLRF No. 415, June 2011, ADA560574.

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8. Warden, R.W., et. al. *"Evaluation of Single Common Powertrain Lubricant (SCPL) Candidates for Fuel Consumption Benefits in Military Equipment,"* Technical paper published in: 2011 NDIA Ground Vehicle Systems Engineering and Technology Symposium (GVSETS), August 2011.

9. Development of Military Fuel/Lubricant/Engine Compatibility Test, CRC Report 406, January 1967.

10. ASTM Deposit Rating Manual 20 (Formerly CRC Manual 20), ASTM International, West Conshohocken, PA, www.astm.org.

11. *"Performance of Engine Lubricating Oils in a Two-Cycle Diesel Engine Under Cyclic, Turbo-Supercharged Conditions"* Federal Test Method STD 791C, Method 355, September 1986.

APPENDIX – A1

EVALUATION OF SCPL CANDIDATE

LO-268869

EVALUATION OF SCPL CANDIDATE LO-268869

Project 14734.17

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-268869
Test Fuel: Jet-A w/DCI-4A
Test Number: LO268869-65T1-W-210
Start of Test Date: August 22, 2011
End of Test Date: September 12, 2011
Test Duration: 210 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Table of Contents

Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-268869 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.17, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing, the engine was disassembled and measured for pre-test wear. Engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure A1-1: Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consisted of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next day's testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified below in Figure A1-2.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure A2-2. Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP-8 blended onsite from Jet A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure A1-3. Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

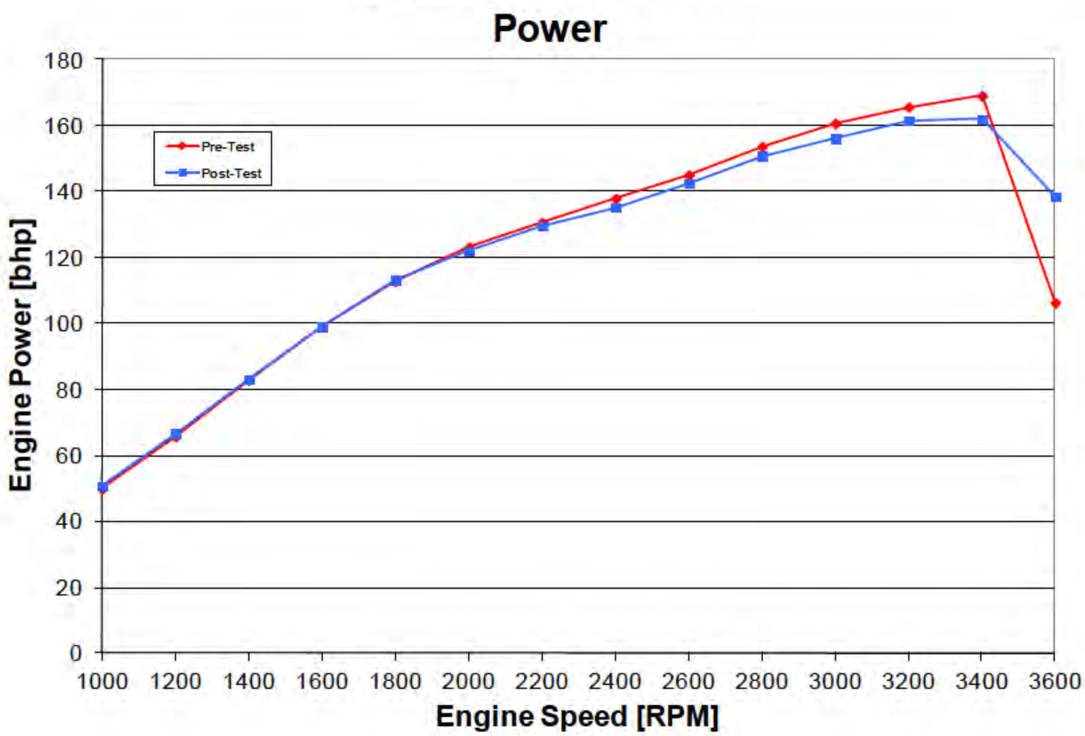
Engine Operating Conditions Summary

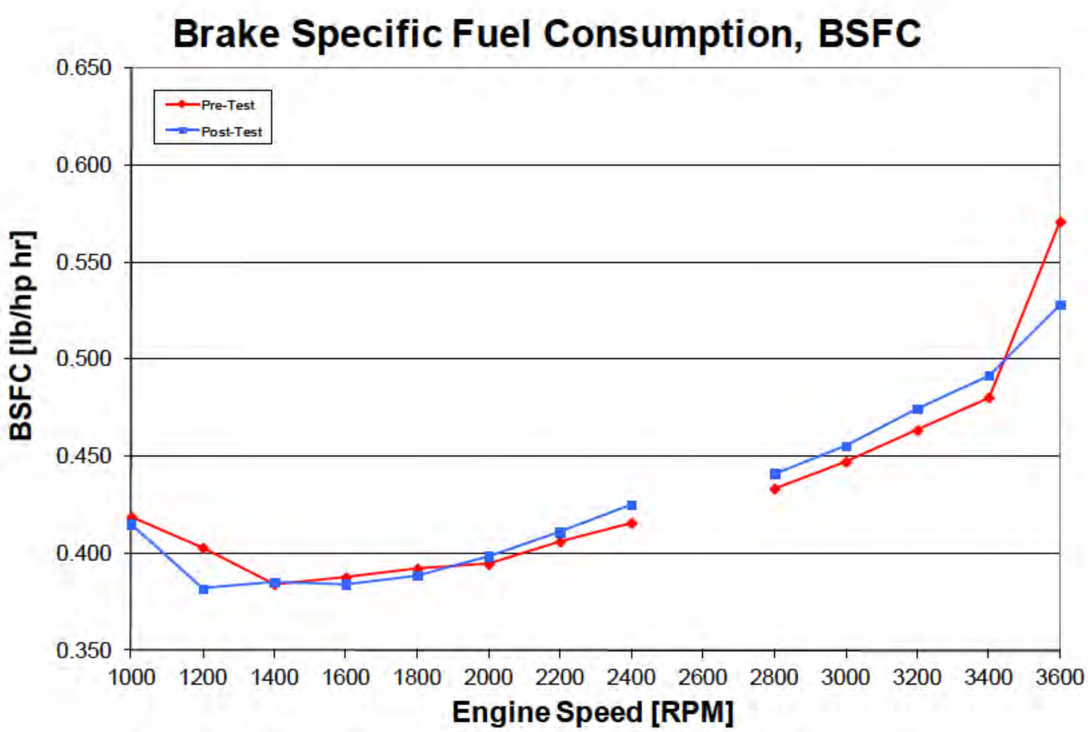
Below is a summary of the engine operating conditions over the test duration. The tested lubricant completed the full 210hr test schedule with satisfactory performance.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.01	0.73	900.21	2.73
Torque*	ft*lb	253.98	2.61	21.78	1.95
Fuel Flow	lb/hr	79.24	0.79	5.54	0.19
Power*	bhp	164.42	1.68	3.73	0.33
BSFC*	lb/bhp*hr	0.482	0.007	1.493	0.103
Temperatures:					
Coolant In	°F	190.06	1.09	91.96	0.89
Coolant Out	°F	205.00	1.01	99.97	0.79
Oil Sump	°F	260.05	0.44	125.61	1.81
Fuel In	°F	95.02	0.31	94.99	0.32
Intake Air	°F	74.94	3.62	72.25	3.25
Cylinder 1 Exhaust	°F	1136.32	15.48	194.86	5.21
Cylinder 2 Exhaust	°F	1204.35	10.67	199.40	6.03
Cylinder 3 Exhaust	°F	1186.67	14.53	211.52	7.07
Cylinder 4 Exhaust	°F	1141.38	14.00	201.10	7.13
Cylinder 5 Exhaust	°F	1152.53	16.09	195.86	8.32
Cylinder 6 Exhaust	°F	1162.03	13.27	197.34	6.78
Cylinder 7 Exhaust	°F	1150.77	14.52	190.82	4.81
Cylinder 8 Exhaust	°F	1147.97	11.32	191.63	5.31
Pressures:					
Oil Galley	psi	35.94	0.56	37.11	3.25
Ambient Pressure	psiA	14.26	0.05	14.25	0.05
Boost Pressure	psi	4.32	0.08	-0.17	0.05

* Non-corrected Values

Engine Performance Curves



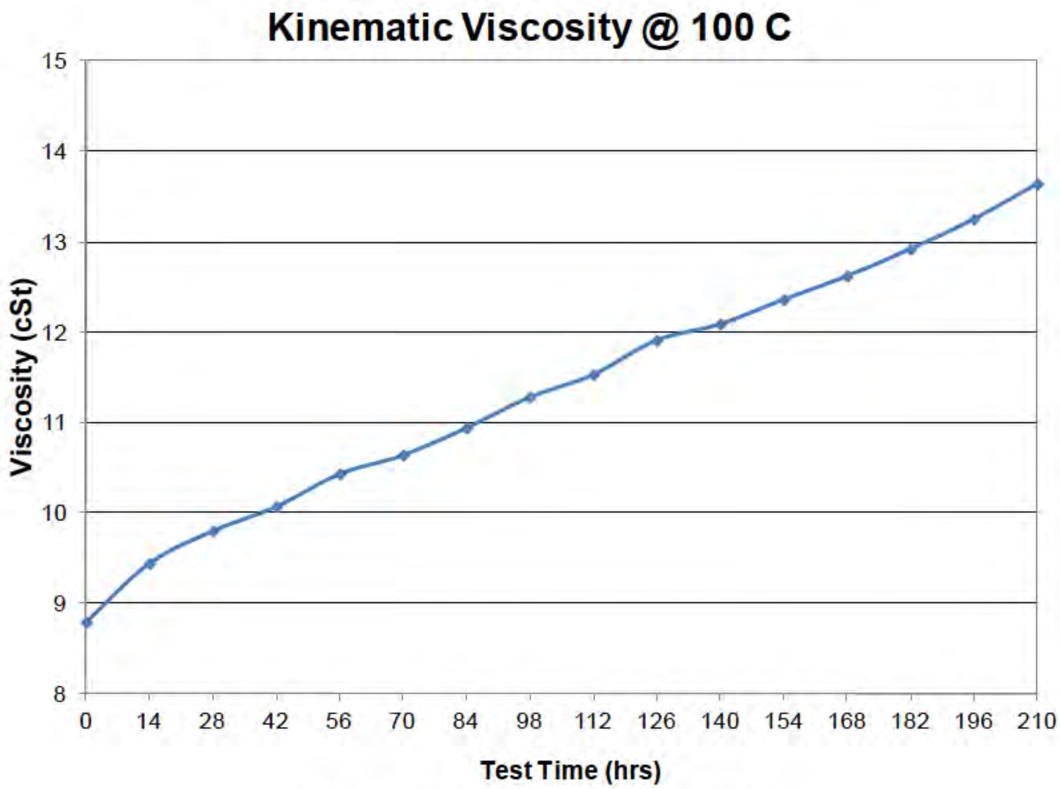


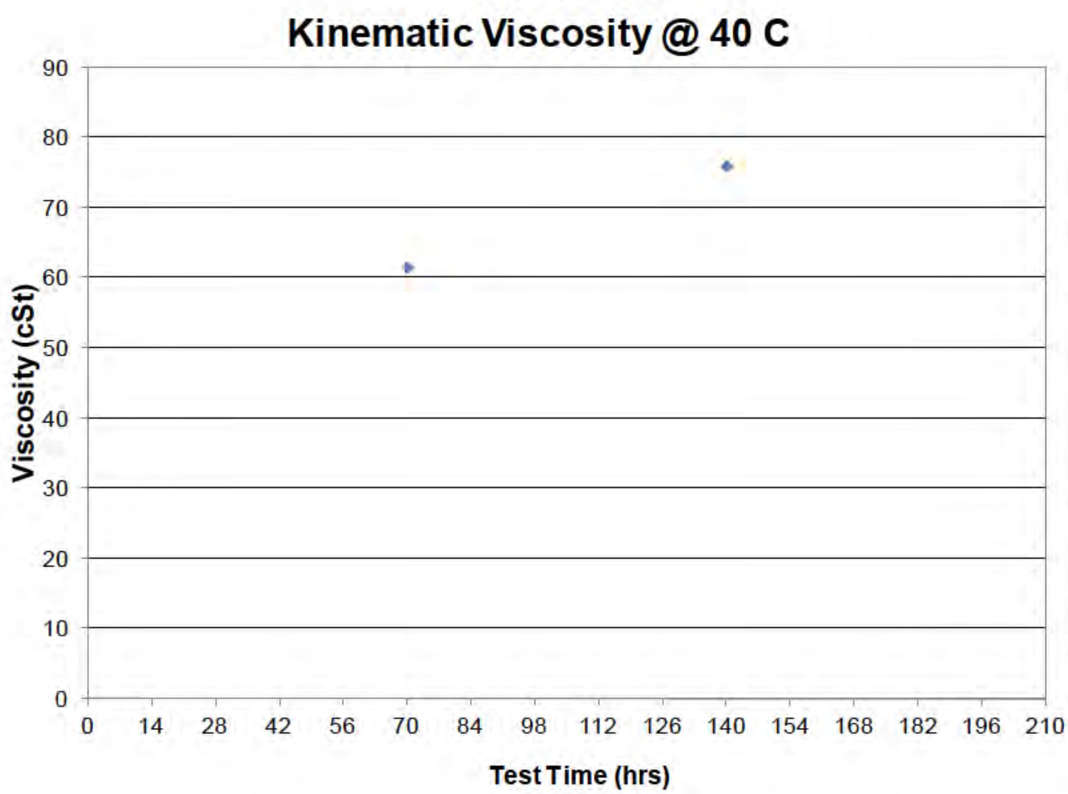
*Note – Breaks in BSFC plot due to invalid values for engine fuel flow during powercurve.

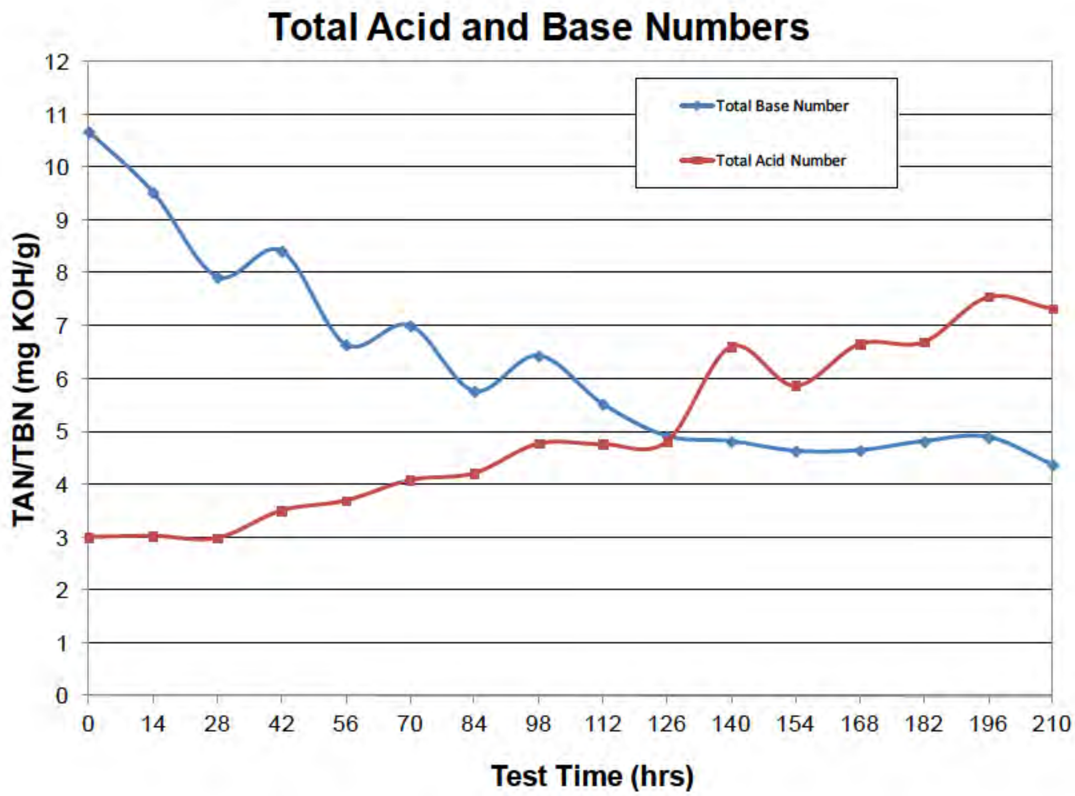
Engine Oil Analysis

Property	ASTM Test	Test Hours															
		0	14	28	42	56	70	84	98	112	126	140	154	168	182	196	210
Density	D4052	0.8562	0.8593	0.8594	0.8625	0.863	0.8662	0.8671	0.8692	0.8721	0.8738	0.8758	0.8783	0.8803	0.8822	0.8847	0.8874
Viscosity @ 100°C (cSt)	D445	8.8	9.4	9.8	10.1	10.4	10.6	10.9	11.3	11.5	11.9	12.1	12.4	12.6	12.9	13.3	13.6
Viscosity @ 40°C (cSt)	D445						61.5					76.0					93.5
Viscosity Index (dyne/cm)	D2270						164.0					156.0					148.0
Total Base Number (mg KOH/g)	D4739	10.7	9.5	7.9	8.4	6.6	7.0	5.8	6.4	5.5	4.9	4.8	4.6	4.6	4.8	4.9	4.4
Total Acid Number (mg KOH/g)	D664	3.0	3.0	3.0	3.5	3.7	4.1	4.2	4.8	4.8	4.8	6.6	5.9	6.7	6.7	7.6	7.3
Oxidation (Abs./cm)	E168 FTNG	0.0	1.2	5.4	9.6	13.7	18.1	22.5	26.6	30.8	35.0	39.9	45.2	50.3	55.3	63.8	68.8
Nitration (Abs./cm)	E168 FTNG	0.0	4.1	5.3	5.2	4.6	4.9	5.4	7.0	8.3	9.8	13.2	15.7	17.5	19.9	23.1	26.0
Soot	Soot	0.2	0.3	0.5	0.6	0.8	0.9	0.9	1.1	1.3	1.5	1.5	1.8	1.9	1.8	2.1	2.1
Wear Metals (ppm)	D5185																
Al		6	7	7	7	8	8	8	9	9	9	10	10	10	11	11	11
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		<1	1	2	3	2	3	5	4	4	3	3	<1	5	3	3	3
Ca		3524	3693	3874	3918	4085	4166	4267	4409	4599	4662	4996	4945	5003	5242	5363	5393
Cr		<1	1	2	3	4	5	5	6	6	7	8	8	8	9	9	10
Cu		<1	28	29	29	34	36	38	38	38	38	39	41	40	41	43	47
Fe		2	46	82	113	144	168	198	223	257	288	328	359	373	400	422	447
Pb		<1	15	17	18	21	24	27	31	34	40	46	52	58	67	78	92
Mg		11	20	16	16	17	19	18	19	19	19	22	21	22	22	21	21
Mn		<1	2	2	3	4	4	4	5	5	6	6	6	6	6	7	7
Mo		<1	10	14	18	21	23	26	27	29	30	32	32	31	32	32	32
Ni		<1	2	3	4	5	5	6	6	7	7	7	8	8	8	8	8
P		1309	1234	1218	1212	1225	1246	1244	1297	1364	1377	1464	1498	1463	1560	1592	1607
Si		2	47	55	56	57	54	57	55	54	52	51	52	49	48	46	46
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		7	6	6	6	6	7	7	7	8	8	10	8	8	10	10	10
Sn		<1	8	10	10	11	12	13	13	14	15	15	17	16	17	17	18
Zn		1873	1874	1932	1897	2043	2078	2119	2236	2274	2342	2449	2603	2547	2621	2652	2747
K		7	7	7	8	8	8	9	8	9	9	10	9	10	10	11	10
Sr		1	2	1	<1	2	1	1	2	1	1	<1	2	2	1	<1	2
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	1	1	1	1	1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

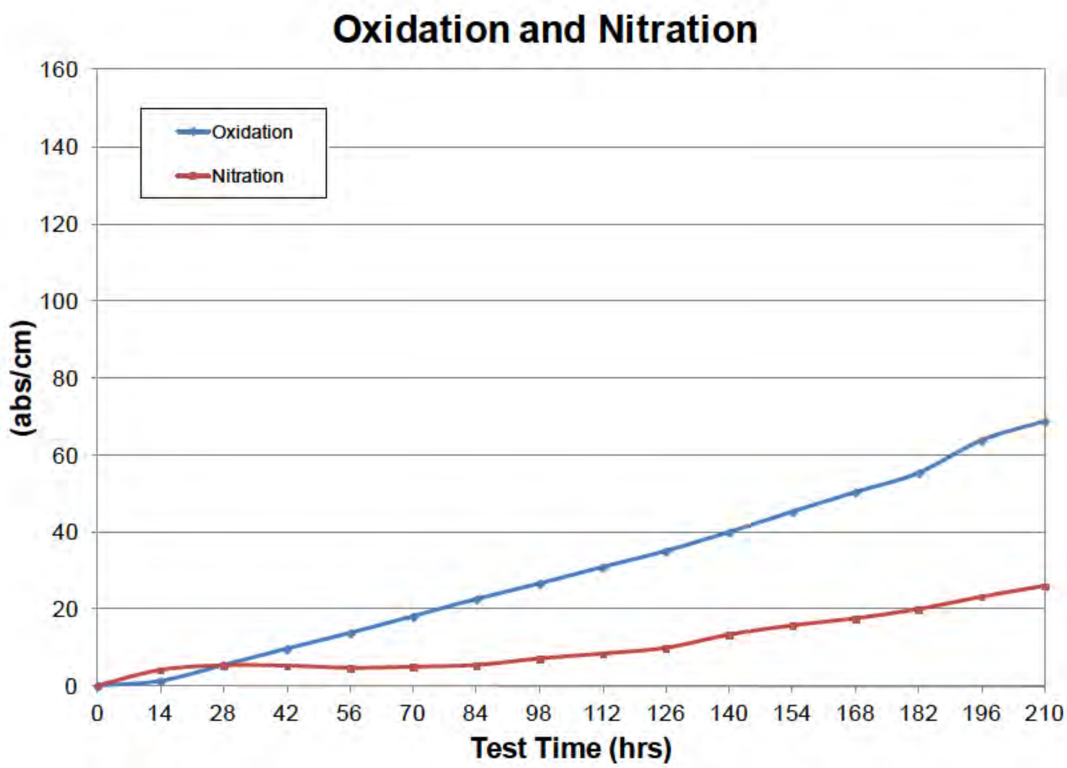
Engine Oil Analysis Trends

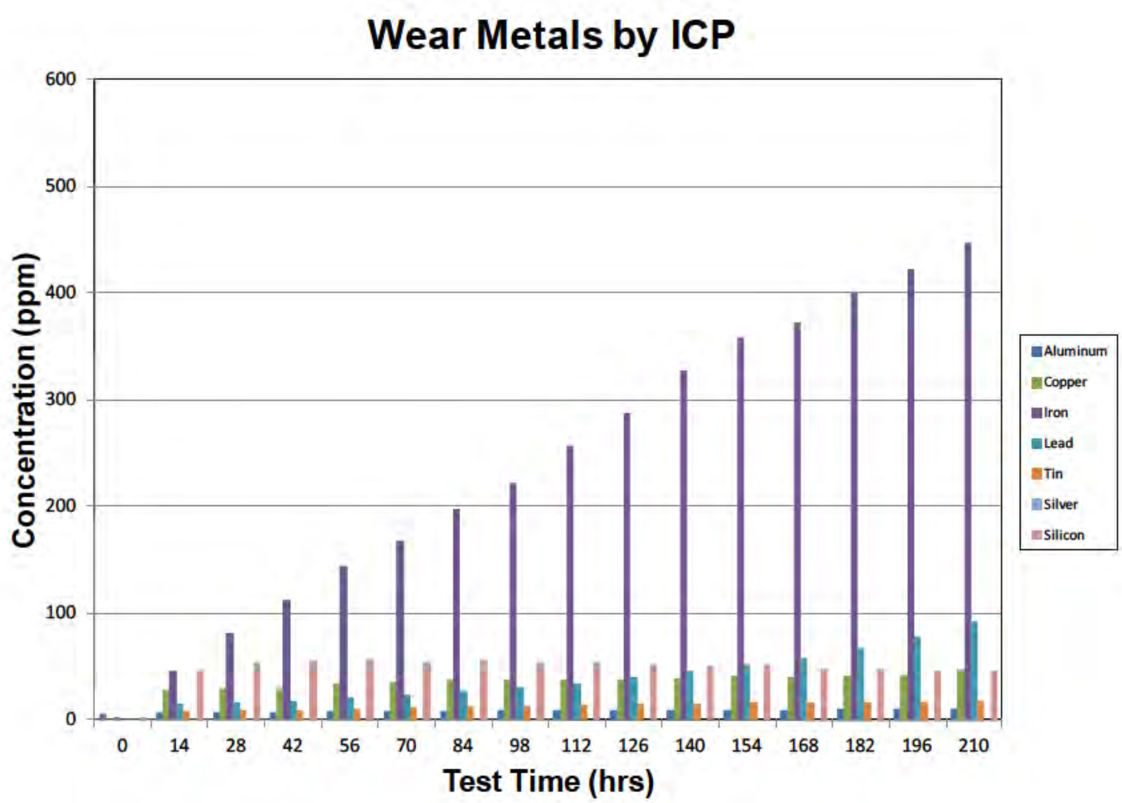





Total Acid and Base Numbers
Total Base Number
Total Acid Number
TAN/TBN (mg KOH/g)
0
1
2
3
4
5
6
7
8
9
10
11
12
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196 210
Test Time (hrs)


Soot
(wt%)
0.0
0.5
1.0
1.5
2.0
2.5
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196 210
Test Time (hrs)


Oxidation and Nitration
(abs/cm)
Oxidation
Nitration
Test Time (hrs)
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
0
20
40
60
80
100
120
140
160


Wear Metals by ICP
Concentration (ppm)
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon
0
100
200
300
400
500
600

Oil Consumption Data

Average oil consumption per test hour was 0.081 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14 -hr	1.38	0.25	1.13	1.13
28 -hr	1.43	0.24	1.19	2.32
42 -hr	1.46	0.22	1.24	3.56
56 -hr	1.46	0.23	1.23	4.79
70 -hr	1.4	0.24	1.16	5.95
84 -hr	1.56	0.25	1.31	7.26
98 -hr	1.49	0.25	1.24	8.5
112 -hr	1.42	0.24	1.18	9.68
126 -hr	1.56	0.25	1.31	10.99
140 -hr	1.39	0.26	1.13	12.12
154 -hr	1.48	0.25	1.23	13.35
168 -hr	1.69	0.25	1.44	14.79
182 -hr	1.71	0.25	1.46	16.25
196 -hr	1.73	0.245	1.485	17.735
210 -hr	2	0.25	1.75	19.485
	Initial Fill	13.31	**Total Additions**	23.16
	EOT Drain	15.85	**Total Samples**	3.675

(Initial Fill + Additions)	36.47
(EOT Drain + Samples)	19.525
Total Oil Consumption	16.945

Post Test Engine Ratings

Ratings	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.2	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.3	NO	NO	NO	NO	NO	NO	NO	NO	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	47.75	80.50	68.75	37.50	78.00	42.50	72.00	57.75	60.59
No.2 Groove	0.05	0.00	10.50	0.00	0.00	0.50	0.50	13.25	3.10
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	38.00	30.25	42.00	45.25	45.50	38.25	54.50	61.25	44.38
No.2 Land	2.50	3.25	24.00	3.75	12.00	6.50	20.00	30.00	12.75
No.3 Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.75	0.34
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.02
No.2 Groove	2.53	3.53	2.82	3.12	3.20	3.12	4.03	1.46	2.98
No.3 Groove	1.50	2.00	1.50	1.50	1.61	2.33	1.50	1.74	1.71
No.1 Land	0.02	0.13	0.02	0.30	0.01	0.02	0.04	0.02	0.07
No.2 Land	2.11	2.73	0.74	2.43	1.53	3.25	0.89	0.48	1.77
No.3 Land	1.73	2.99	1.72	2.33	1.68	2.27	1.84	2.07	2.08
Upper Skirt	0.66	0.66	0.86	0.73	0.33	0.66	0.39	0.77	0.63
Under Crown	2.70	3.40	3.85	3.10	5.02	3.55	2.98	4.52	3.64
Front Pin Bore	1.40	1.33	1.40	1.40	1.13	1.40	1.50	1.40	1.37
Rear Pin Bore	1.40	1.40	1.67	1.40	1.40	1.67	1.40	1.40	1.47
Total, Demerits	102.35	132.17	159.83	102.81	151.41	106.02	161.75	178.86	136.90
Miscellanous									
Top Groove Fill, %	44	75	69	29	65	42	73	56	56.63
Intermediate Groove Fill, %	0	0	5	0	0	0	0	14	2.38
Top Land Heavy Carbon, %	18	10	24	29	28	19	40	49	27.13
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0	0	0.00
Valve Tulip Deposits, Merits									
Exahust	9.0	9.3	9.2	9.0	9.5	9.5	9.0	9.0	9.19
Intake	7.8	8.7	7.1	8.0	7.1	6.2	6.0	7.3	7.28

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0547	4.0555	4.0550	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0001	0.0007	0.0004	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0001	0.0005	0.0003	
Piston Skirt Diameter	4.0496	4.0499	4.0497	
Piston Skirt to Cylinder Bore Clearance	0.0050	0.0058	0.0053	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.012	0.016	0.014	
Second Ring	0.033	0.038	0.035	
Oil Control Ring	0.012	0.016	0.014	
Ring To Groove Clearance				
Second Ring	0.0020	0.0020	0.0020	0.0015"-0.003"
Oil Control Ring	0.0016	0.0020	0.0019	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2215	1.2216	1.2216	1.2207"-1.2212"
Piston Pin Clearance	0.0010	0.0011	0.0011	0.0003"-0.0012"
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2215	1.2216	1.2215	1.2207"-1.2212"
Piston Pin Clearance	0.0010	0.0011	0.0010	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0025	0.0030	0.0027	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0030	0.0022	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.006	0.004-0.010"
Rod Side Clearance	0.008	0.009	0.009	0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0549	4.0547		0.0002
	Middle	4.0548	4.0544	4.0548	0.0004
	Bottom	4.0548	4.0546		0.0002
	Taper	0.0001	0.0003		
2	Top	4.0548	4.0547		0.0001
	Middle	4.0547	4.0543	4.0547	0.0004
	Bottom	4.0546	4.0545		0.0001
	Taper	0.0002	0.0004		
3	Top	4.0552	4.0545		0.0007
	Middle	4.0549	4.0542	4.0549	0.0007
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0004	0.0003		
4	Top	4.0549	4.0545		0.0004
	Middle	4.0548	4.0542	4.0548	0.0006
	Bottom	4.0547	4.0545		0.0002
	Taper	0.0002	0.0003		
5	Top	4.0552	4.0546		0.0006
	Middle	4.0550	4.0543	4.0550	0.0007
	Bottom	4.0549	4.0547		0.0002
	Taper	0.0003	0.0004		
6	Top	4.0551	4.0546		0.0005
	Middle	4.0548	4.0543	4.0548	0.0005
	Bottom	4.0547	4.0546		0.0001
	Taper	0.0004	0.0003		
7	Top	4.0556	4.0555		0.0001
	Middle	4.0555	4.0550	4.0555	0.0005
	Bottom	4.0555	4.0551		0.0004
	Taper	0.0001	0.0005		
8	Top	4.0556	4.0553		0.0003
	Middle	4.0555	4.0548	4.0555	0.0007
	Bottom	4.0554	4.0550		0.0004
	Taper	0.0002	0.0005		

Post-Test Cylinder Bore Measurements, in

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0551	4.0547		0.0004
	Middle	4.0548	4.0544	4.0548	0.0004
	Bottom	4.0547	4.0547		0.0000
	Taper	0.0004	0.0003		
2	Top	4.0552	4.0547		0.0005
	Middle	4.0551	4.0544	4.0550	0.0007
	Bottom	4.0549	4.0547		0.0002
	Taper	0.0003	0.0003		
3	Top	4.0555	4.0545		0.0010
	Middle	4.0550	4.0542	4.0549	0.0008
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0007	0.0003		
4	Top	4.0551	4.0547		0.0004
	Middle	4.0550	4.0543	4.0550	0.0007
	Bottom	4.0549	4.0547		0.0002
	Taper	0.0002	0.0004		
5	Top	4.0554	4.0547		0.0007
	Middle	4.0550	4.0543	4.0550	0.0007
	Bottom	4.0549	4.0548		0.0001
	Taper	0.0005	0.0005		
6	Top	4.0557	4.0546		0.0011
	Middle	4.0552	4.0543	4.0551	0.0009
	Bottom	4.0549	4.0547		0.0002
	Taper	0.0008	0.0004		
7	Top	4.0558	4.0555		0.0003
	Middle	4.0555	4.0550	4.0555	0.0005
	Bottom	4.0554	4.0552		0.0002
	Taper	0.0004	0.0005		
8	Top	4.0559	4.0553		0.0006
	Middle	4.0558	4.0548	4.0557	0.0010
	Bottom	4.0555	4.0553		0.0002
	Taper	0.0004	0.0005		

Cylinder Bore Diameter Changes, in

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0002	0.0000	
	Middle	0.0000	0.0000	0.0000
	Bottom	0.0001	0.0001	
2	Top	0.0004	0.0000	
	Middle	0.0004	0.0001	0.0004
	Bottom	0.0003	0.0002	
3	Top	0.0003	0.0000	
	Middle	0.0001	0.0000	0.0000
	Bottom	0.0000	0.0000	
4	Top	0.0002	0.0002	
	Middle	0.0002	0.0001	0.0002
	Bottom	0.0002	0.0002	
5	Top	0.0002	0.0001	
	Middle	0.0000	0.0000	0.0000
	Bottom	0.0000	0.0001	
6	Top	0.0006	0.0000	
	Middle	0.0004	0.0000	0.0003
	Bottom	0.0002	0.0001	
7	Top	0.0002	0.0000	
	Middle	0.0000	0.0000	0.0001
	Bottom	0.0001	0.0001	
8	Top	0.0003	0.0000	
	Middle	0.0003	0.0000	0.0002
	Bottom	0.0001	0.0003	
Avgerage All Cylinders	Top	0.0003	0.0000	
	Middle	0.0002	0.0000	
	Bottom	0.0001	0.0001	

Valve Guide Measurement Changes, in

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3424	0.4240	0.0816	0.3726	0.3728	0.0002
2	0.3425	0.3425	0.0000	0.3725	0.3728	0.0003
3	0.3425	0.3424	-0.0001	0.3726	0.3728	0.0002
4	0.3424	0.3424	0.0000	0.3726	0.3729	0.0003
5	0.3424	0.3424	0.0000	0.3726	0.3728	0.0002
6	0.3425	0.3425	0.0000	0.3725	0.3729	0.0004
7	0.3425	0.3425	0.0000	0.3726	0.3728	0.0002
8	0.3424	0.3424	0.0000	0.3726	0.3728	0.0002

Maximum	0.0816
Average	0.0102

Maximum	0.0004
Average	0.0003

Valve Stem Measurement Changes, in

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3414	0.3411	0.0003	0.3711	0.3710	0.0001
2	0.3414	0.3410	0.0004	0.3712	0.3710	0.0002
3	0.3414	0.3412	0.0002	0.3712	0.3706	0.0006
4	0.3413	0.3409	0.0004	0.3712	0.3709	0.0003
5	0.3413	0.3411	0.0002	0.3712	0.3711	0.0001
6	0.3414	0.3410	0.0004	0.3711	0.3711	0.0000
7	0.3414	0.3411	0.0003	0.3711	0.3710	0.0001
8	0.3414	0.3410	0.0004	0.3712	0.3709	0.0003

Maximum	0.0004
Average	0.0003

Maximum	0.0006
Average	0.0002

Valve Stem to Guide Clearance Changes, in

	Stem/Guide Clearance Intake			Stem Guide Clearance Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0010	0.0829	0.0819	0.0015	0.0018	0.0003
2	0.0011	0.0015	0.0004	0.0013	0.0018	0.0005
3	0.0011	0.0012	0.0001	0.0014	0.0022	0.0008
4	0.0011	0.0015	0.0004	0.0014	0.0020	0.0006
5	0.0011	0.0013	0.0002	0.0014	0.0017	0.0003
6	0.0011	0.0015	0.0004	0.0014	0.0018	0.0004
7	0.0011	0.0014	0.0003	0.0015	0.0018	0.0003
8	0.0010	0.0014	0.0004	0.0014	0.0019	0.0005

Maximum	0.0819
Average	0.0105

Maximum	0.0008
Average	0.0005

Valve Recession Measurement Changes, in

	Valve Recession Intake			Valve Recession Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.024	0.062	0.038	0.027	0.037	0.010
2	0.025	0.065	0.040	0.026	0.028	0.002
3	0.025	0.055	0.030	0.027	0.029	0.002
4	0.024	0.042	0.018	0.027	0.027	0.000
5	0.024	0.062	0.038	0.028	0.036	0.008
6	0.025	0.040	0.015	0.027	0.027	0.000
7	0.022	0.043	0.021	0.025	0.029	0.004
8	0.024	0.048	0.024	0.026	0.030	0.004

Maximum	0.040
Average	0.028

Maximum	0.010
Average	0.004

Post-Test Cam Lobe Profile, in

Cam Lobe	Waviness Parameter [µm]
1	1.73
2	1.24
3	1.47
4	1.17
5	1.66
6	2.21
7	1.82
8	1.31
9	2.24
10	1.43
11	0.91
12	1.24
13	2.06
14	2.98
15	1.59
16	1.42

Maximum	2.98
Average	1.66

Piston Skirt to Bore Clearance, in

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0548	4.0497	0.0051
	2	4.0547	4.0497	0.0050
	3	4.0549	4.0497	0.0052
	4	4.0548	4.0497	0.0051
	5	4.0550	4.0499	0.0050
	6	4.0548	4.0496	0.0052
	7	4.0555	4.0497	0.0058
	8	4.0555	4.0497	0.0058
Post - Test	1	4.0548	4.0493	0.0055
	2	4.0550	4.0492	0.0058
	3	4.0549	4.0493	0.0056
	4	4.0550	4.0491	0.0058
	5	4.0550	4.0493	0.0057
	6	4.0551	4.0491	0.0059
	7	4.0555	4.0494	0.0061
	8	4.0557	4.0493	0.0064

Top and Second Ring Radial Wear, in

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.17780	0.17705	0.00075
	2	0.17770	0.17695	0.00075
	3	0.17650	0.17595	0.00055
	4	0.17750	0.17710	0.00040
	5	0.17740	0.17690	0.00050
2	1	0.17830	0.17770	0.00060
	2	0.17855	0.17800	0.00055
	3	0.17880	0.17815	0.00065
	4	0.17835	0.17795	0.00040
	5	0.17780	0.17730	0.00050
3	1	0.17855	0.17815	0.00040
	2	0.17925	0.17885	0.00040
	3	0.17840	0.17790	0.00050
	4	0.17815	0.17755	0.00060
	5	0.17830	0.17780	0.00050
4	1	0.17905	0.17865	0.00040
	2	0.17975	0.17952	0.00023
	3	0.17875	0.17845	0.00030
	4	0.17825	0.17760	0.00065
	5	0.17845	0.17805	0.00040
5	1	0.17865	0.17815	0.00050
	2	0.18005	0.17940	0.00065
	3	0.18015	0.17960	0.00055
	4	0.17970	0.17895	0.00075
	5	0.17870	0.17830	0.00040
6	1	0.17955	0.17905	0.00050
	2	0.17795	0.17745	0.00050
	3	0.17895	0.17815	0.00080
	4	0.17990	0.17925	0.00065
	5	0.17970	0.17920	0.00050
7	1	0.17890	0.17850	0.00040
	2	0.17870	0.17825	0.00045
	3	0.17890	0.17835	0.00055
	4	0.17875	0.17845	0.00030
	5	0.17905	0.17855	0.00050
8	1	0.17790	0.17725	0.00065
	2	0.17750	0.17700	0.00050
	3	0.17805	0.17745	0.00060
	4	0.17880	0.17835	0.00045
	5	0.17800	0.17735	0.00065
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.00080
Average	0.00052

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16210	0.16150	0.00060
	2	0.16200	0.16155	0.00045
	3	0.15990	0.15950	0.00040
	4	0.15920	0.15885	0.00035
	5	0.16105	0.16070	0.00035
2	1	0.16165	0.16120	0.00045
	2	0.16290	0.16225	0.00065
	3	0.16030	0.15985	0.00045
	4	0.16010	0.15960	0.00050
	5	0.16125	0.16080	0.00045
3	1	0.16155	0.16080	0.00075
	2	0.16075	0.16020	0.00055
	3	0.16040	0.15970	0.00070
	4	0.16185	0.16150	0.00035
	5	0.16150	0.16100	0.00050
4	1	0.16190	0.16125	0.00065
	2	0.16140	0.16085	0.00055
	3	0.16070	0.15985	0.00085
	4	0.16100	0.16040	0.00060
	5	0.16175	0.16130	0.00045
5	1	0.16230	0.16185	0.00045
	2	0.16315	0.16245	0.00070
	3	0.16145	0.16080	0.00065
	4	0.16120	0.16055	0.00065
	5	0.16175	0.16120	0.00055
6	1	0.16200	0.16140	0.00060
	2	0.16230	0.16205	0.00025
	3	0.16020	0.15970	0.00050
	4	0.16075	0.16010	0.00065
	5	0.16220	0.16145	0.00075
7	1	0.16215	0.16145	0.00070
	2	0.16227	0.16205	0.00022
	3	0.16155	0.16105	0.00050
	4	0.16075	0.16025	0.00050
	5	0.16215	0.16165	0.00050
8	1	0.16125	0.16085	0.00040
	2	0.16190	0.16165	0.00025
	3	0.16025	0.15990	0.00035
	4	0.16160	0.16120	0.00040
	5	0.16115	0.16100	0.00015
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.00085
Average	0.00051

Piston Ring Gap Measurements, in

Cylinder	Ring No.	Before	After	Delta
1	1	0.013	0.016	0.003
	2	0.033	0.037	0.004
	3	0.013	0.015	0.002
2	1	0.013	0.016	0.003
	2	0.033	0.038	0.005
	3	0.013	0.015	0.002
3	1	0.012	0.016	0.004
	2	0.035	0.037	0.002
	3	0.013	0.016	0.003
4	1	0.013	0.017	0.004
	2	0.034	0.038	0.004
	3	0.013	0.016	0.003
5	1	0.013	0.015	0.002
	2	0.038	0.042	0.004
	3	0.014	0.016	0.002
6	1	0.013	0.020	0.007
	2	0.035	0.036	0.001
	3	0.014	0.017	0.003
7	1	0.016	0.018	0.002
	2	0.038	0.041	0.003
	3	0.016	0.018	0.002
8	1	0.016	0.020	0.004
	2	0.034	0.039	0.005
	3	0.012	0.017	0.005

Ring No. 1 max increase	0.007
Ring No. 2 max increase	0.005
Ring No. 3 max increase	0.005

Ring No. 1 avg increase	0.004
Ring No. 2 avg increase	0.004
Ring No. 3 avg increase	0.003

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.7541	22.6533	0.1008
	2	17.0669	17.0356	0.0313
	3	15.2482	15.2357	0.0125
2	1	22.8106	22.7119	0.0987
	2	17.0748	17.0382	0.0366
	3	14.9461	14.9318	0.0143
3	1	22.8003	22.7104	0.0899
	2	17.0292	16.9901	0.0391
	3	15.3226	15.3044	0.0182
4	1	22.8790	22.7945	0.0845
	2	17.0481	17.0143	0.0338
	3	14.9637	14.9467	0.0170
5	1	22.8445	22.7391	0.1054
	2	17.1074	17.0637	0.0437
	3	15.3087	15.2923	0.0164
6	1	22.8318	22.7400	0.0918
	2	17.0351	16.9959	0.0392
	3	15.0681	15.0518	0.0163
7	1	22.8722	22.7913	0.0809
	2	17.0542	17.0209	0.0333
	3	15.2659	15.2512	0.0147
8	1	22.8376	22.7511	0.0865
	2	17.0606	17.0295	0.0311
	3	15.3035	15.2847	0.0188

Ring No. 1 max decrease	0.1054
Ring No. 2 max decrease	0.0437
Ring No. 3 max decrease	0.0188

Ring No. 1 avg decrease	0.0923
Ring No. 2 avg decrease	0.0360
Ring No. 3 avg decrease	0.0160

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.5997	27.5758	0.0239
	Bottom	27.5825	27.5719	0.0106
2	Top	27.5555	27.5383	0.0172
	Bottom	27.5790	27.5702	0.0088
3	Top	27.6239	27.5766	0.0473
	Bottom	27.5660	27.5299	0.0361
4	Top	27.5801	27.5626	0.0175
	Bottom	27.6037	27.5913	0.0124
5	Top	27.5768	27.5493	0.0275
	Bottom	27.5344	27.5210	0.0134
6	Top	27.4884	27.4620	0.0264
	Bottom	27.6483	27.6330	0.0153
7	Top	27.5598	27.5348	0.0250
	Bottom	27.6727	27.6538	0.0189
8	Top	27.6420	27.6278	0.0142
	Bottom	27.6912	27.6782	0.0130

Maximum	0.0473
Average	0.0205

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.1879	48.1408	0.0471
	Bottom	51.7463	51.6480	0.0983
2	Top	48.0748	48.0425	0.0323
	Bottom	51.5846	51.3740	0.2106
3	Top	97.7533	97.4820	0.2713
	Bottom	103.4375	103.0981	0.3394
4	Top	47.9910	47.9638	0.0272
	Bottom	51.5284	51.3870	0.1414
5	Top	69.0709	69.0106	0.0603
	Bottom	72.9269	72.8335	0.0934

Maximum	0.3394
Average	0.1321

Stanadyne Injection Pump Calibration/Evaluation

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 15714947**
Test condition :	**AL:**

PUMP RPM	Description	Spec.	Before	After	Change
1000	Transfer pump psi.	60-62 psi	62	61	1
	Return Fuel	225-375 cc	260	270	10
350	Low Idle	12-16 cc	15	7.5	7.5
	Housing psi.	8-12 psi	10	11	1
	Advance	3.5 deg. min	2.5	2.98	0.48
	Cold Advance Solenoid	0-1 psi.	0	0	0
750	Shut-Off	4 cc max.	0	0	0
900	Fuel Delivery	66.5 - 69.5cc	66	66	0
1600	WOT Fuel delivery	59.5 min.	64	64	0
	WOT Advance	2.5 - 3.5 deg.	3.03	3.2	0.17
	Face Cam Fuel delivery	21.5 - 23.5	22	22	0
	Face Cam Advance	5.25 - 7.25 deg.	6.15	6.1	0.05
	Low Idle	11 - 12 deg.	11.03	11.01	0.02
1825	Fuel Delivery	33 cc min.	38	39	1
1950	High Idle	15 cc max.	2	2	0
	Transfer pump psi.	125 psi max.	112	111	1
200	WOT Fuel Delivery	58 cc min.	60	60	0
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	48	48	0
	Transfer pump psi.	16 psi min.	24	22	2
	Housing psi.	0 -12 psi	10	10	0
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5	-0.5	0

*Pump calibration data to be used for reference only

PHOTOGRAPHS

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	9-12-11
Test No.:	LO268869-65T1-W-210	**Test Length:**	210

Piston Skirt Thrust - Best Cyl 1

Piston Skirt Anti-thrust - Best Cyl 1

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	9-12-11
Test No.:	LO268869-65T1-W-210	**Test Length:**	210

Piston Skirt Thrust - Worst Cyl 8

Piston Skirt Anti-thrust - Worst Cyl 8

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	9-12-11
Test No.:	LO268869-65T1-W-210	**Test Length:**	210

Piston Rings - Best Cyl 7

Piston Rings - Worst Cyl 5

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO268869	EOT Date:	9-12-11
Test No.:	LO268869-65T1-W-210	Test Length:	210

Piston Undercrown - Best Cyl 1

Piston Undercrown - Worst Cyl 8

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	9-12-11
Test No.:	LO268869-65T1-W-210	**Test Length:**	210

Engine Block Cylinder Bore - Best   Cyl 5

Engine Block Cylinder Bore - Worst   Cyl 8

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	9-12-11
Test No.:	LO268869-65T1-W-210	**Test Length:**	210

Exhaust and Intake Valve - Best Cyl 2

Oil Code:	LO268869	EOT Date:	9-12-11
Test No.:	LO268869-65T1-W-210	Test Length:	210

Exhaust and Intake Valve - Worst Cyl 7

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	9-12-11
Test No.:	LO268869-65T1-W-210	**Test Length:**	210

Rod Bearings

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO268869	EOT Date:	9-12-11
Test No.:	LO268869-65T1-W-210	Test Length:	210

Main Bearings

APPENDIX – A2
EVALUATION OF SCPL CANDIDATE
LO-271510

EVALUATION OF SCPL CANDIDATE LO-271510

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-271510
Test Fuel: Jet-A w/DCI-4A
Test Number: LO271510-65T1-W-210
Start of Test Date: October 11, 2011
End of Test Date: October 31, 2011
Test Duration: 196 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Table of Contents

Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-271510 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing, the engine was disassembled and measured for pre-test wear. Engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

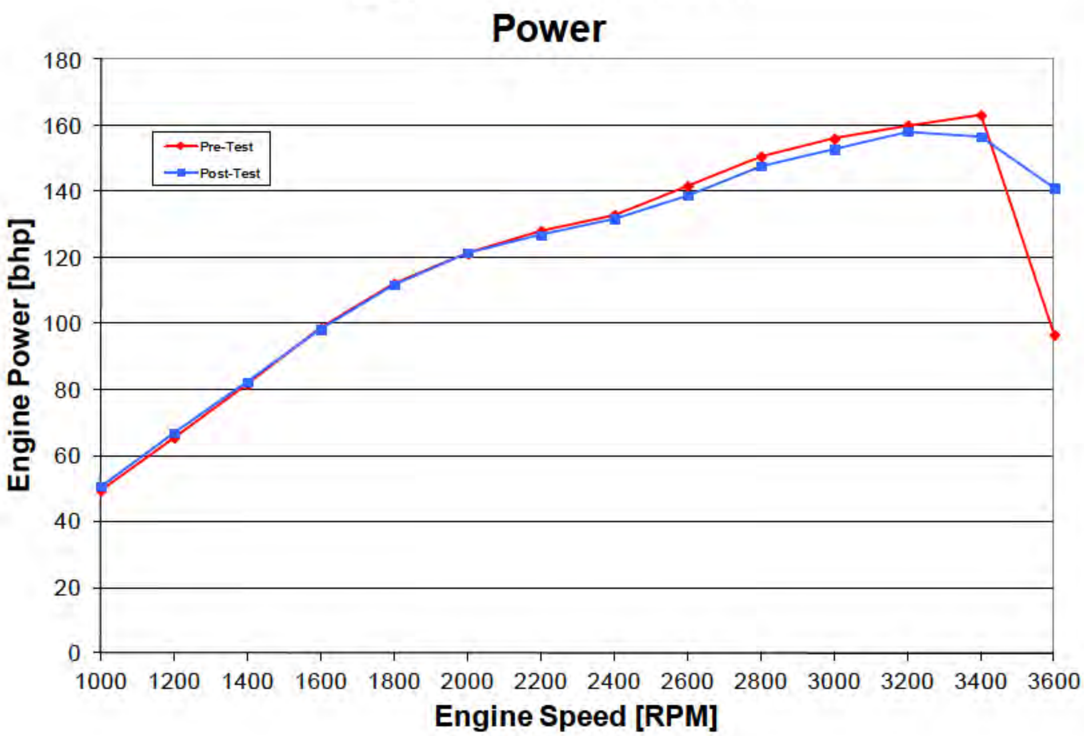
Engine Operating Conditions Summary

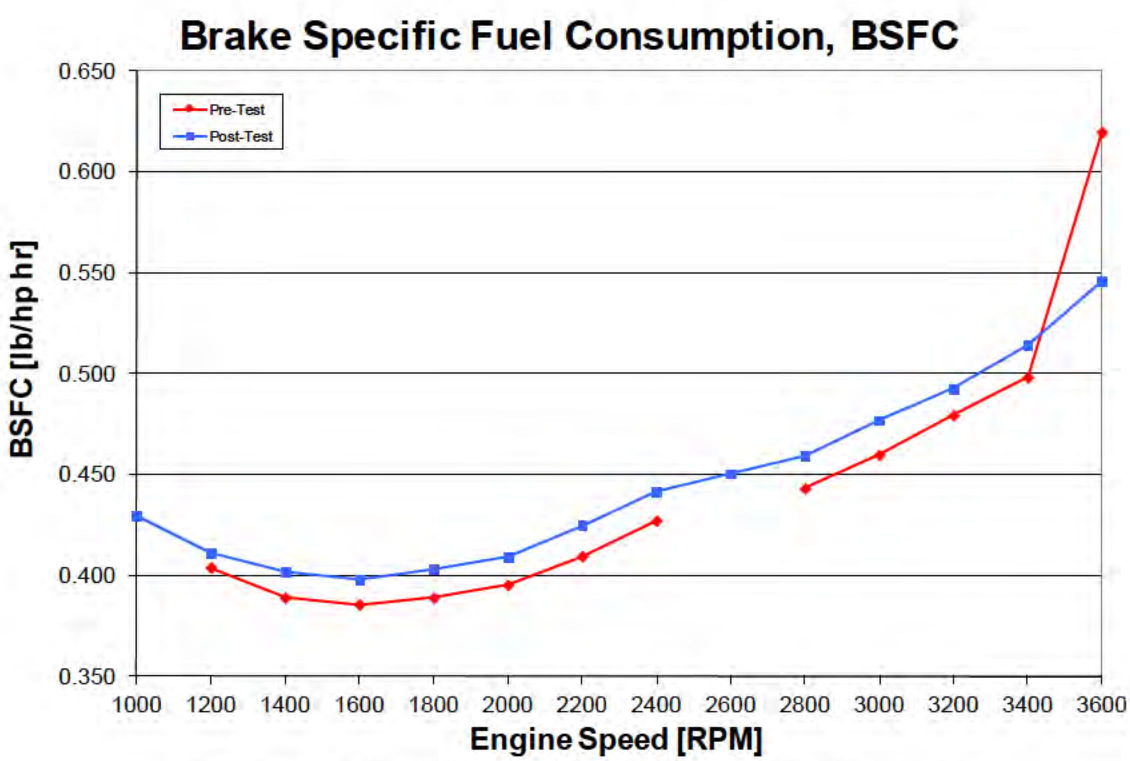
Below is a summary of the engine operating conditions over the test duration. The tested lubricant completed 196hrs of the scheduled 210hr test before being stopped due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.01	0.76	900.58	5.12
Torque*	ft*lb	254.23	2.88	26.49	1.94
Fuel Flow	lb/hr	80.52	0.83	5.79	6.54
Power*	bhp	164.58	1.86	4.55	0.33
BSFC*	lb/bhp*hr	0.489	0.006	1.282	1.453
Temperatures:					
Coolant In	°F	190.40	0.92	92.28	0.93
Coolant Out	°F	204.99	0.84	100.00	0.80
Oil Sump	°F	260.05	0.50	125.59	1.94
Fuel In	°F	95.01	0.34	94.98	0.32
Intake Air	°F	68.33	3.34	65.14	3.14
Cylinder 1 Exhaust	°F	1135.40	16.16	180.81	4.02
Cylinder 2 Exhaust	°F	1205.01	13.90	181.45	4.63
Cylinder 3 Exhaust	°F	1206.48	16.88	185.56	4.70
Cylinder 4 Exhaust	°F	1144.29	15.49	194.32	6.49
Cylinder 5 Exhaust	°F	1162.88	14.26	187.07	4.81
Cylinder 6 Exhaust	°F	1166.94	17.23	196.79	5.34
Cylinder 7 Exhaust	°F	1144.28	18.44	186.20	4.77
Cylinder 8 Exhaust	°F	1164.26	13.81	186.75	4.35
Pressures:					
Oil Galley	psi	36.96	1.59	40.60	5.59
Ambient Pressure	psiA	14.30	0.07	14.30	0.07
Boost Pressure	psi	4.84	0.12	-0.14	0.06

* Non-corrected Values

Engine Performance Curves



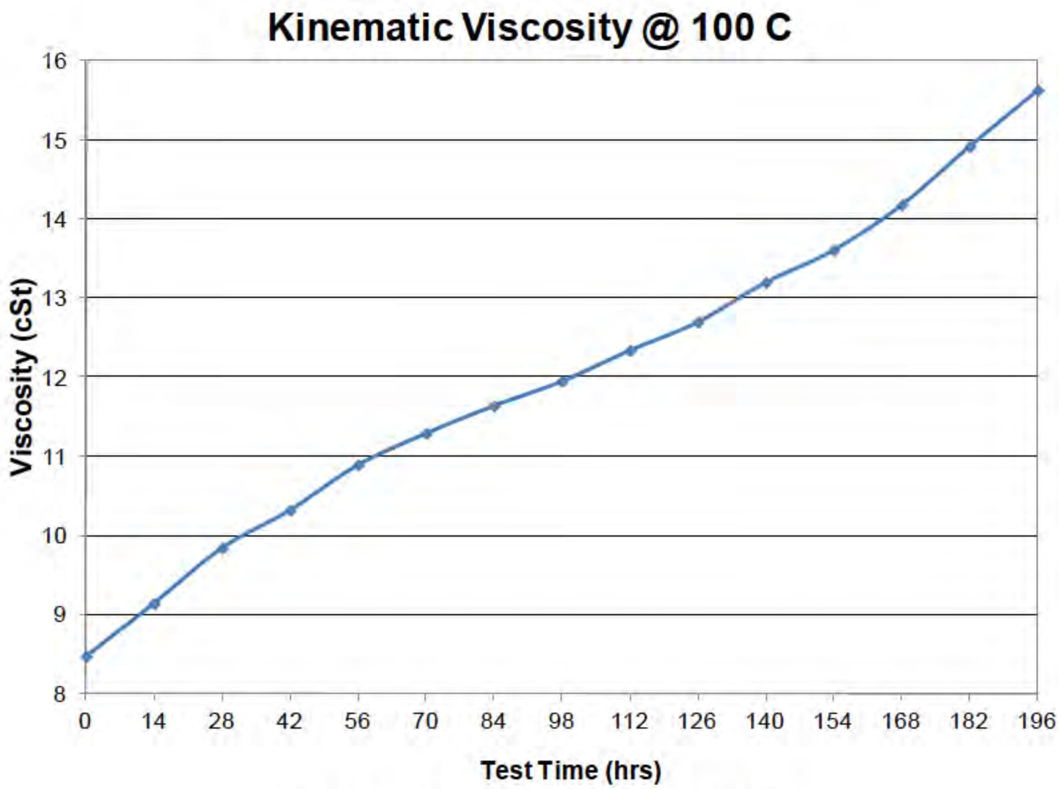


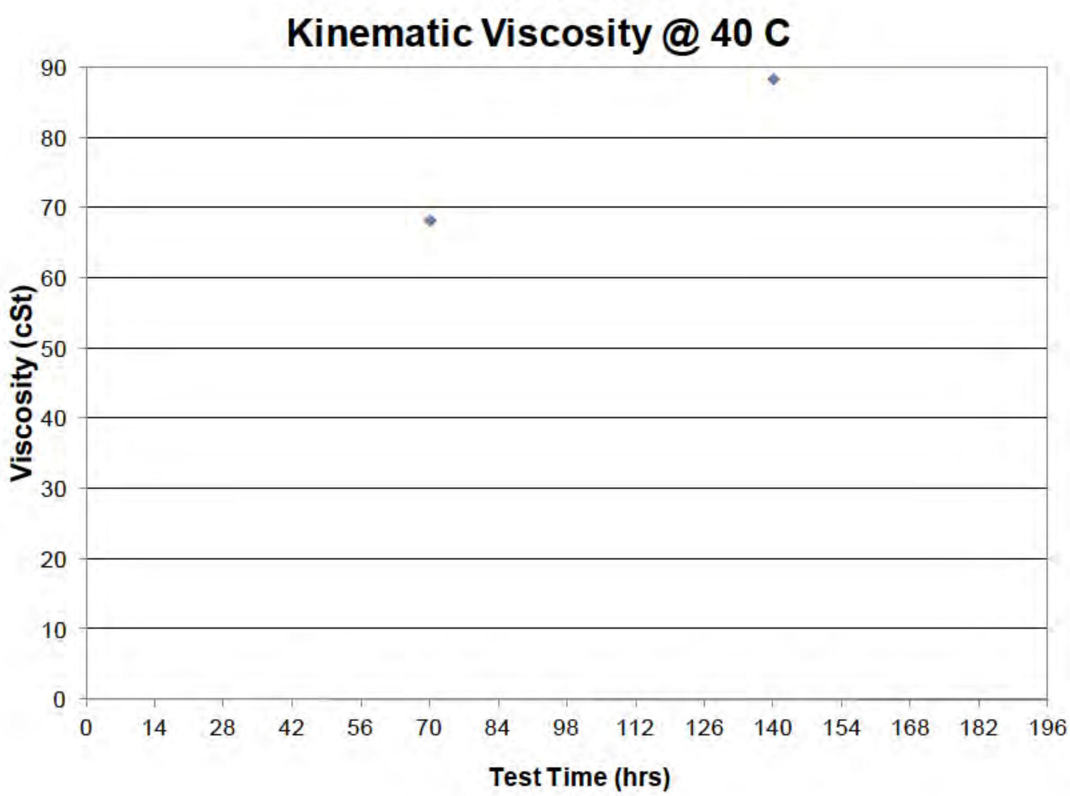
*Note – Breaks in BSFC plot due to invalid values for engine fuel flow during powercurve.

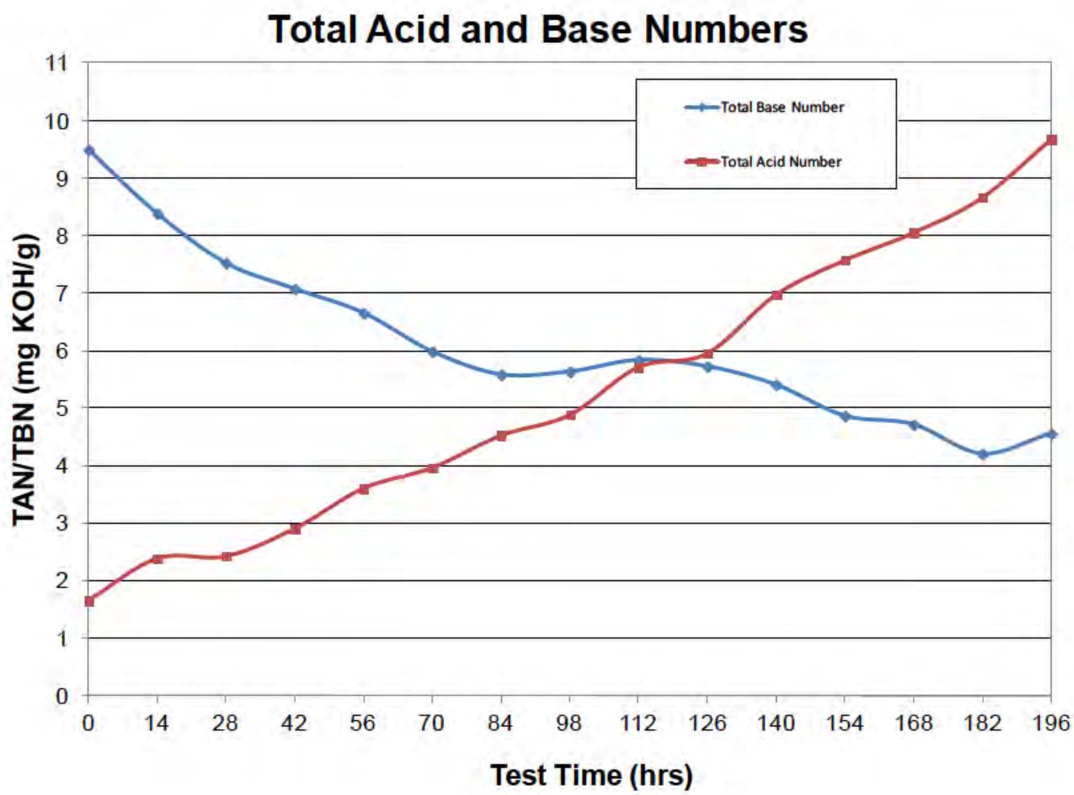
Engine Oil Analysis

Property	ASTM Test	Test Hours														
		0	14	28	42	56	70	84	98	112	126	140	154	168	182	196
Density	D4052	0.8466	0.8512	0.8552	0.8582	0.861	0.864	0.8667	0.8693	0.8717	0.8752	0.8796	0.8831	0.887	0.8908	0.894
Viscosity @ 100°C (cSt)	D445	8.5	9.1	9.8	10.3	10.9	11.3	11.6	12.0	12.3	12.7	13.2	13.6	14.2	14.9	15.6
Viscosity @ 40°C (cSt)	D445						68.3					88.4				
Viscosity Index (dyne/cm)	D2270						159.0					150.0				
Total Base Number (mg KOH/g)	D4739	9.5	8.4	7.5	7.1	6.7	6.0	5.6	5.6	5.8	5.7	5.4	4.9	4.7	4.2	4.6
Total Acid Number (mg KOH/g)	D664	1.7	2.4	2.4	2.9	3.6	4.0	4.5	4.9	5.7	6.0	7.0	7.6	8.1	8.7	9.7
Oxidation (Abs./cm)	E168 FTNG	0.0	6.9	13.3	18.7	24.2	31.5	37.3	43.7	50.3	58.8	69.6	80.4	91.3	103.0	111.7
Nitration (Abs./cm)	E168 FTNG	0.0	5.6	6.2	7.3	9.8	15.0	18.2	21.8	26.6	33.7	39.7	44.1	48.0	51.2	52.0
Soot	Soot	0.2	0.4	0.6	0.8	1.0	1.1	1.3	1.4	1.6	1.7	1.8	2.2	2.3	2.4	2.6
Wear Metals (ppm)	D5185															
Al		2	4	4	4	5	5	5	5	5	5	5	5	4	4	5
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		14	14	16	15	18	16	17	17	17	17	18	17	18	19	22
Ca		902	1012	1013	1080	1081	1172	1206	1204	1254	1291	1312	1355	1422	1436	1469
Cr		<1	2	2	3	4	4	4	5	5	5	6	5	6	6	6
Cu		<1	33	36	36	37	39	40	39	39	40	42	43	47	52	61
Fe		1	54	85	112	136	173	200	217	239	270	297	323	366	398	452
Pb		<1	19	24	27	29	34	38	41	45	56	74	94	128	174	232
Mg		1259	1330	1392	1453	1485	1583	1617	1644	1700	1756	1806	1841	1915	1926	1995
Mn		<1	2	2	3	3	4	4	4	4	4	5	5	5	6	6
Mo		64	78	88	96	98	105	110	111	110	120	122	120	128	130	132
Ni		<1	3	4	5	6	6	7	7	7	8	8	8	8	8	9
P		1079	1083	1076	1104	1079	1169	1207	1214	1223	1304	1350	1336	1463	1474	1476
Si		5	53	64	69	67	71	71	68	63	65	63	59	57	55	56
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		<5	<5	<5	5	5	6	7	6	7	7	8	8	9	10	9
Sn		<1	8	10	10	11	12	12	12	12	13	14	14	13	14	15
Zn		1265	1324	1379	1453	1506	1564	1611	1648	1691	1752	1812	1867	1876	1878	1979
K		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sr		<1	<1	<1	<1	1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

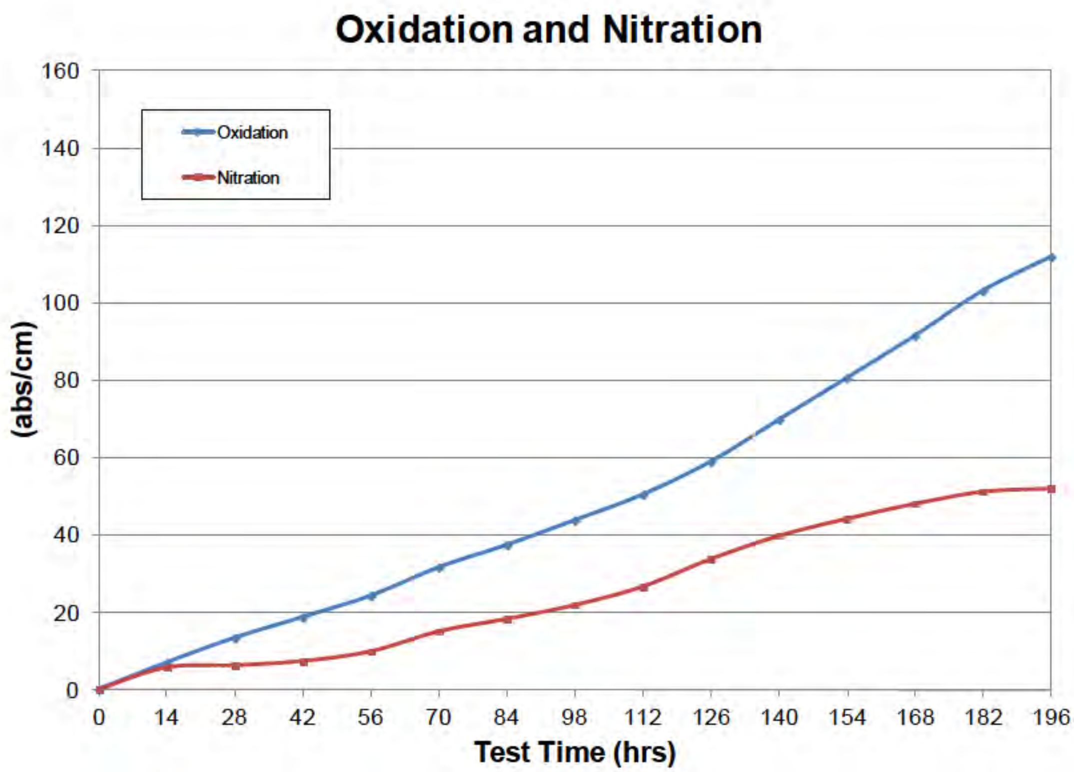
Engine Oil Analysis Trends

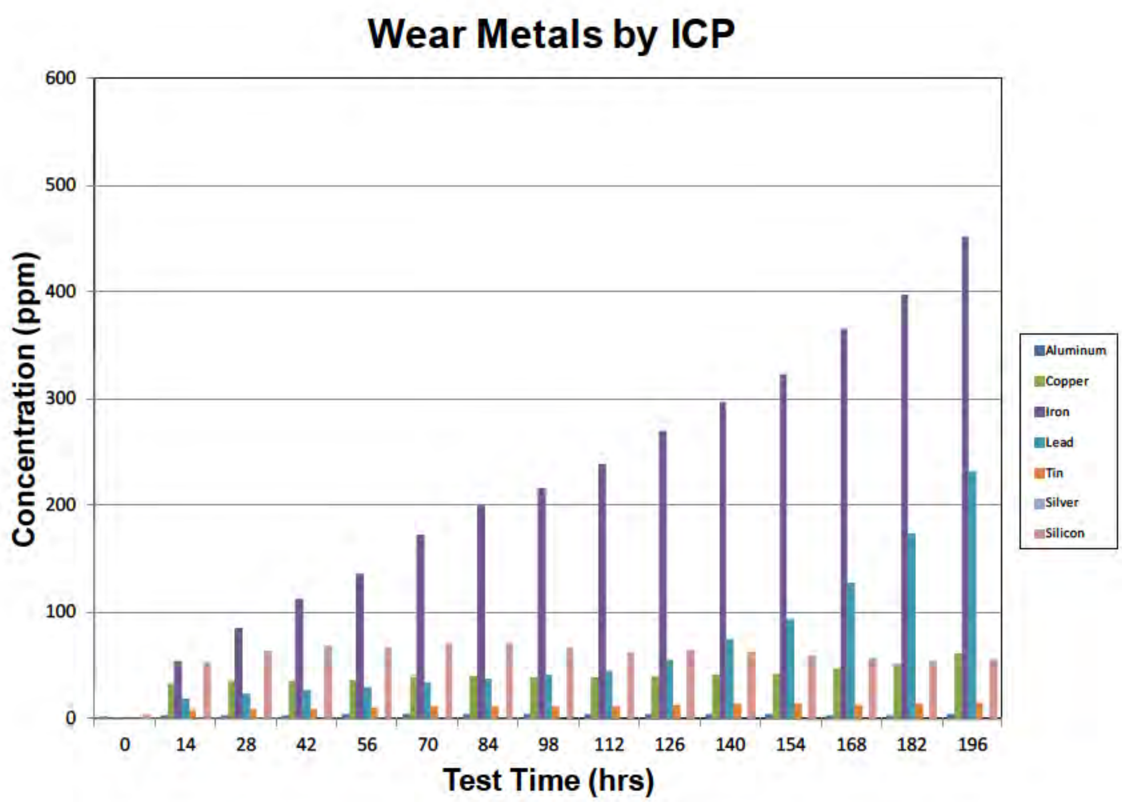





Total Acid and Base Numbers
Total Base Number
Total Acid Number
TAN/TBN (mg KOH/g)
Test Time (hrs)
0
1
2
3
4
5
6
7
8
9
10
11
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196


Soot
(wt%)
Test Time (hrs)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196


Oxidation and Nitration
Oxidation
Nitration
(abs/cm)
Test Time (hrs)
0
20
40
60
80
100
120
140
160
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196


Wear Metals by ICP
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon
Concentration (ppm)
Test Time (hrs)
0
100
200
300
400
500
600
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196

Oil Consumption Data

Average oil consumption per test hour was 0.084 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14 -hr	1.24	0.235	1.005	1.005
28 -hr	1.63	0.22	1.41	2.415
42 -hr	1.61	0.21	1.4	3.815
56 -hr	1.2	0.22	0.98	4.795
70 -hr	1.64	0.21	1.43	6.225
84 -hr	1.61	0.23	1.38	7.605
98 -hr	1.62	0.23	1.39	8.995
112 -hr	1.44	0.22	1.22	10.215
126 -hr	1.57	0.25	1.32	11.535
140 -hr	1.65	0.26	1.39	12.925
154 -hr	1.7	0.26	1.44	14.365
168 -hr	1.61	0.26	1.35	15.715
182 -hr	1.69	0.235	1.455	17.17
196 -hr	1.61	0.25	1.36	18.53
	Initial Fill	13.33	**Total Additions**	21.82
	EOT Drain	15.36	**Total Samples**	3.29

(Initial Fill + Additions)	35.15
(EOT Drain + Samples)	18.65
Total Oil Consumption	16.5

Post Test Engine Ratings

Ratings	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.2	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.3	NO	NO	NO	NO	NO	NO	NO	NO	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	44.75	47.50	65.75	59.50	35.50	52.25	33.25	51.25	48.72
No.2 Groove	0.00	0.50	10.00	1.25	2.25	5.25	0.00	10.00	3.66
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	30.00	28.75	40.50	35.75	39.50	36.50	27.25	38.75	34.63
No.2 Land	7.25	11.25	13.50	2.25	17.25	15.00	6.75	22.00	11.91
No.3 Land	0.00	0.00	0.50	0.00	1.00	1.25	0.00	0.50	0.41
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.50	1.56
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	3.67	2.09	2.59	2.93	1.98	2.14	3.00	1.84	2.53
No.3 Groove	2.10	1.60	1.90	1.84	1.20	1.99	1.80	2.20	1.83
No.1 Land	0.04	0.03	0.02	0.01	0.01	0.02	0.06	0.01	0.03
No.2 Land	1.96	1.13	0.92	1.74	0.92	1.47	1.63	0.64	1.30
No.3 Land	1.24	1.69	1.96	1.52	1.70	2.37	1.50	2.34	1.79
Upper Skirt	0.33	0.68	0.64	0.70	0.50	0.77	0.55	0.99	0.65
Under Crown	5.13	4.13	4.87	3.06	3.11	4.44	4.07	2.10	3.86
Front Pin Bore	1.36	1.36	1.36	1.40	1.78	1.36	1.36	1.78	1.47
Rear Pin Bore	1.78	1.36	1.10	1.10	1.36	1.78	1.36	1.36	1.40
Total, Demerits	99.61	102.07	145.61	113.05	108.06	126.59	82.58	148.26	115.73
Miscellanous									
Top Groove Fill, %	41	40	65	41	29	40	22	43	40.13
Intermediate Groove Fill, %	0	0	7	0	0	1	0	4	1.50
Top Land Heavy Carbon, %	8	7	22	15	20	17	7	19	14.38
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0	0	0.00
Valve Tulip Deposits, Merits									
Exahust	9.0	9.1	9.1	9.0	9.0	9.0	9.0	9.1	9.04
Intake	7.0	7.6	7.7	6.8	6.8	8.7	7.1	7.0	7.34

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0546	4.0555	4.0549	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0001	0.0045	0.0006	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0001	0.0042	0.0005	
Piston Skirt Diameter	4.0499	4.0504	4.0502	
Piston Skirt to Cylinder Bore Clearance	0.0044	0.0051	0.0047	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.013	0.016	0.015	
Second Ring	0.032	0.039	0.035	
Oil Control Ring	0.013	0.015	0.014	
Ring To Groove Clearance				
Second Ring	0.0020	0.0020	0.0020	0.0015"-0.003"
Oil Control Ring	0.0016	0.0020	0.0019	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2216	1.2218	1.2217	1.2207"-1.2212"
Piston Pin Clearance	0.0011	0.0013	0.0012	0.0003"-0.0012"
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2217	1.2218	1.2218	1.2207"-1.2212"
Piston Pin Clearance	0.0012	0.0013	0.0013	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0025	0.0030	0.0028	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0030	0.0022	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.007	0.004-0.010"
Rod Side Clearance	0.009	0.010	0.010	0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0549	4.0546		0.0003
	Middle	4.0548	4.0543	4.0548	0.0005
	Bottom	4.0547	4.0546		0.0001
	Taper	0.0002	0.0003		
2	Top	4.0548	4.0545		0.0003
	Middle	4.0547	4.0541	4.0547	0.0006
	Bottom	4.0547	4.0544		0.0003
	Taper	0.0001	0.0004		
3	Top	4.0550	4.0545		0.0005
	Middle	4.0548	4.0542	4.0548	0.0006
	Bottom	4.0547	4.0545		0.0002
	Taper	0.0003	0.0003		
4	Top	4.0548	4.0545		0.0003
	Middle	4.0547	4.0541	4.0546	0.0006
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0003	0.0004		
5	Top	4.0551	4.0545		0.0006
	Middle	4.0549	4.0542	4.0549	0.0007
	Bottom	4.0548	4.0546		0.0002
	Taper	0.0003	0.0004		
6	Top	4.0550	4.0545		0.0005
	Middle	4.0548	4.0541	4.0548	0.0007
	Bottom	4.0547	4.0544		0.0003
	Taper	0.0003	0.0004		
7	Top	4.0556	4.0552		0.0004
	Middle	4.0555	4.0548	4.0555	0.0007
	Bottom	4.0555	4.0510		0.0045
	Taper	0.0001	0.0042		
8	Top	4.0556	4.0551		0.0005
	Middle	4.0554	4.0547	4.0554	0.0007
	Bottom	4.0553	4.0551		0.0002
	Taper	0.0003	0.0004		

Post-Test Cylinder Bore Measurements, in

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0553	4.0546		0.0007
	Middle	4.0549	4.0543	4.0549	0.0006
	Bottom	4.0548	4.0548		0.0000
	Taper	0.0005	0.0005		
2	Top	4.0555	4.0546		0.0009
	Middle	4.0551	4.0541	4.0550	0.0010
	Bottom	4.0549	4.0546		0.0003
	Taper	0.0006	0.0005		
3	Top	4.0555	4.0545		0.0010
	Middle	4.0551	4.0542	4.0549	0.0009
	Bottom	4.0547	4.0546		0.0001
	Taper	0.0008	0.0004		
4	Top	4.0551	4.0547		0.0004
	Middle	4.0550	4.0541	4.0550	0.0009
	Bottom	4.0549	4.0547		0.0002
	Taper	0.0002	0.0006		
5	Top	4.0554	4.0545		0.0009
	Middle	4.0552	4.0543	4.0551	0.0009
	Bottom	4.0549	4.0548		0.0001
	Taper	0.0005	0.0005		
6	Top	4.0556	4.0545		0.0011
	Middle	4.0553	4.0541	4.0551	0.0012
	Bottom	4.0549	4.0548		0.0001
	Taper	0.0007	0.0007		
7	Top	4.0560	4.0553		0.0007
	Middle	4.0557	4.0548	4.0557	0.0009
	Bottom	4.0557	4.0552		0.0005
	Taper	0.0003	0.0005		
8	Top	4.0560	4.0553		0.0007
	Middle	4.0557	4.0547	4.0557	0.0010
	Bottom	4.0556	4.0552		0.0004
	Taper	0.0004	0.0006		

Cylinder Bore Diameter Changes, in

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0004	0.0000	
	Middle	0.0001	0.0000	0.0001
	Bottom	0.0001	0.0002	
2	Top	0.0007	0.0001	
	Middle	0.0004	0.0000	0.0003
	Bottom	0.0002	0.0002	
3	Top	0.0005	0.0000	
	Middle	0.0003	0.0000	0.0002
	Bottom	0.0000	0.0001	
4	Top	0.0003	0.0002	
	Middle	0.0003	0.0000	0.0003
	Bottom	0.0004	0.0003	
5	Top	0.0003	0.0000	
	Middle	0.0003	0.0001	0.0002
	Bottom	0.0001	0.0002	
6	Top	0.0006	0.0000	
	Middle	0.0005	0.0000	0.0003
	Bottom	0.0002	0.0004	
7	Top	0.0004	0.0001	
	Middle	0.0002	0.0000	0.0002
	Bottom	0.0002	0.0042	
8	Top	0.0004	0.0002	
	Middle	0.0003	0.0000	0.0003
	Bottom	0.0003	0.0001	
Avgerage All Cylinders	Top	0.0005	0.0001	
	Middle	0.0003	0.0000	
	Bottom	0.0002	0.0007	

Valve Guide Measurement Changes, in

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3424	0.3424	0.0000	0.3726	0.3729	0.0003
2	0.3425	0.3425	0.0000	0.3726	0.3728	0.0002
3	0.3424	0.3425	0.0001	0.3725	0.3729	0.0004
4	0.3424	0.3425	0.0001	0.3725	0.3728	0.0003
5	0.3425	0.3426	0.0001	0.3726	0.3728	0.0002
6	0.3425	0.3425	0.0000	0.3725	0.3729	0.0004
7	0.3425	0.3425	0.0000	0.3725	0.3728	0.0003
8	0.3425	0.3425	0.0000	0.3726	0.3728	0.0002

Maximum	0.0001	Maximum	0.0004
Average	0.0000	Average	0.0003

Valve Stem Measurement Changes, in

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3414	0.3409	0.0005	0.3711	0.3709	0.0002
2	0.3414	0.3409	0.0005	0.3712	0.3709	0.0003
3	0.3414	0.3410	0.0004	0.3712	0.3708	0.0004
4	0.3414	0.3411	0.0003	0.3711	0.3708	0.0003
5	0.3414	0.3411	0.0003	0.3712	0.3708	0.0004
6	0.3414	0.3410	0.0004	0.3711	0.3708	0.0003
7	0.3414	0.3409	0.0005	0.3711	0.3708	0.0003
8	0.3414	0.3410	0.0004	0.3712	0.3708	0.0004

Maximum	0.0005	Maximum	0.0004
Average	0.0004	Average	0.0003

Valve Stem to Guide Clearance Changes, in

	Stem/Guide Clearance Intake			Stem Guide Clearance Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0010	0.0015	0.0005	0.0015	0.0020	0.0005
2	0.0011	0.0016	0.0005	0.0014	0.0019	0.0005
3	0.0010	0.0015	0.0005	0.0013	0.0021	0.0008
4	0.0010	0.0014	0.0004	0.0014	0.0020	0.0006
5	0.0011	0.0015	0.0004	0.0014	0.0020	0.0006
6	0.0011	0.0015	0.0004	0.0014	0.0021	0.0007
7	0.0011	0.0016	0.0005	0.0014	0.0020	0.0006
8	0.0011	0.0015	0.0004	0.0014	0.0020	0.0006

Maximum	0.0005
Average	0.0004

Maximum	0.0008
Average	0.0006

Valve Recession Measurement Changes, in

	Valve Recession Intake			Valve Recession Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.025	0.049	0.024	0.027	0.055	0.028
2	0.024	0.070	0.046	0.026	0.029	0.003
3	0.026	0.047	0.021	0.028	0.092	0.064
4	0.022	0.072	0.050	0.028	0.042	0.014
5	0.024	0.059	0.035	0.025	0.047	0.022
6	0.024	0.059	0.035	0.026	0.045	0.019
7	0.026	0.065	0.039	0.025	0.061	0.036
8	0.023	0.052	0.029	0.026	0.065	0.039

Maximum	0.050
Average	0.035

Maximum	0.064
Average	0.028

Post-Test Cam Lobe Profile, in

Cam Lobe	Waviness Parameter [µm]
1	1.07
2	0.95
3	0.92
4	1.32
5	0.83
6	1.44
7	1.01
8	1.23
9	1.18
10	1.03
11	1.06
12	1.05
13	1.10
14	1.14
15	1.25
16	1.02

Maximum	1.44
Average	1.10

Piston Skirt to Bore Clearance, in

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0548	4.0500	0.0048
	2	4.0547	4.0503	0.0044
	3	4.0548	4.0499	0.0049
	4	4.0546	4.0501	0.0045
	5	4.0549	4.0502	0.0046
	6	4.0548	4.0501	0.0047
	7	4.0555	4.0504	0.0051
	8	4.0554	4.0503	0.0050
Post - Test	1	4.0549	4.0493	0.0056
	2	4.0550	4.0491	0.0059
	3	4.0549	4.0488	0.0061
	4	4.0550	4.0491	0.0058
	5	4.0551	4.0493	0.0057
	6	4.0551	4.0488	0.0063
	7	4.0557	4.0494	0.0063
	8	4.0557	4.0495	0.0061

Top and Second Ring Radial Wear, in

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.17790	0.17760	0.00030
	2	0.17840	0.17790	0.00050
	3	0.17790	0.17765	0.00025
	4	0.17687	0.17655	0.00032
	5	0.17790	0.17750	0.00040
2	1	0.17965	0.17925	0.00040
	2	0.18005	0.17975	0.00030
	3	0.17905	0.17850	0.00055
	4	0.17880	0.17840	0.00040
	5	0.17895	0.17860	0.00035
3	1	0.17730	0.17700	0.00030
	2	0.17755	0.17680	0.00075
	3	0.17675	0.17665	0.00010
	4	0.17770	0.17720	0.00050
	5	0.17690	0.17655	0.00035
4	1	0.17775	0.17710	0.00065
	2	0.17835	0.17810	0.00025
	3	0.17860	0.17795	0.00065
	4	0.17745	0.17680	0.00065
	5	0.17760	0.17690	0.00070
5	1	0.17825	0.17770	0.00055
	2	0.17815	0.17770	0.00045
	3	0.17820	0.17775	0.00045
	4	0.17915	0.17865	0.00050
	5	0.17875	0.17810	0.00065
6	1	0.17845	0.17790	0.00055
	2	0.17835	0.17785	0.00050
	3	0.17855	0.17790	0.00065
	4	0.17935	0.17880	0.00055
	5	0.17855	0.17815	0.00040
7	1	0.17805	0.17750	0.00055
	2	0.17920	0.17875	0.00045
	3	0.17925	0.17860	0.00065
	4	0.17875	0.17825	0.00050
	5	0.17830	0.17775	0.00055
8	1	0.17900	0.17850	0.00050
	2	0.17855	0.17795	0.00060
	3	0.17765	0.17710	0.00055
	4	0.17860	0.17795	0.00065
	5	0.17820	0.17765	0.00055
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.00075
Average	0.00049

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16240	0.16180	0.00060
	2	0.16145	0.16125	0.00020
	3	0.16035	0.15990	0.00045
	4	0.16145	0.16105	0.00040
	5	0.16245	0.16190	0.00055
2	1	0.16100	0.16065	0.00035
	2	0.16160	0.16140	0.00020
	3	0.16035	0.16010	0.00025
	4	0.16100	0.16010	0.00090
	5	0.16140	0.16105	0.00035
3	1	0.16200	0.16135	0.00065
	2	0.16140	0.16105	0.00035
	3	0.15990	0.15945	0.00045
	4	0.16055	0.16020	0.00035
	5	0.16195	0.16125	0.00070
4	1	0.16255	0.16180	0.00075
	2	0.16225	0.16150	0.00075
	3	0.16085	0.16050	0.00035
	4	0.16065	0.16015	0.00050
	5	0.16160	0.16130	0.00030
5	1	0.16235	0.16200	0.00035
	2	0.16225	0.16190	0.00035
	3	0.16200	0.16155	0.00045
	4	0.16200	0.16165	0.00035
	5	0.16235	0.16210	0.00025
6	1	0.16200	0.16160	0.00040
	2	0.16210	0.16170	0.00040
	3	0.16150	0.16105	0.00045
	4	0.16230	0.16180	0.00050
	5	0.16195	0.16145	0.00050
7	1	0.16235	0.16165	0.00070
	2	0.16215	0.16180	0.00035
	3	0.16050	0.16000	0.00050
	4	0.16070	0.16020	0.00050
	5	0.16165	0.16130	0.00035
8	1	0.16230	0.16175	0.00055
	2	0.16225	0.16185	0.00040
	3	0.16155	0.16110	0.00045
	4	0.16175	0.16120	0.00055
	5	0.16235	0.16165	0.00070
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.00090
Average	0.00046

Piston Ring Gap Measurements, in

Cylinder	Ring No.	Before	After	Delta
1	1	0.015	0.019	0.004
	2	0.039	0.036	-0.003
	3	0.014	0.017	0.003
2	1	0.013	0.016	0.003
	2	0.033	0.037	0.004
	3	0.013	0.014	0.001
3	1	0.015	0.019	0.004
	2	0.037	0.037	0.000
	3	0.013	0.015	0.002
4	1	0.014	0.018	0.004
	2	0.033	0.037	0.004
	3	0.013	0.014	0.001
5	1	0.014	0.017	0.003
	2	0.033	0.036	0.003
	3	0.014	0.015	0.001
6	1	0.014	0.018	0.004
	2	0.032	0.037	0.005
	3	0.013	0.015	0.002
7	1	0.015	0.019	0.004
	2	0.036	0.040	0.004
	3	0.015	0.019	0.004
8	1	0.016	0.019	0.003
	2	0.035	0.039	0.004
	3	0.013	0.016	0.003

Ring No. 1 max increase	0.004
Ring No. 2 max increase	0.005
Ring No. 3 max increase	0.004

Ring No. 1 avg increase	0.004
Ring No. 2 avg increase	0.003
Ring No. 3 avg increase	0.002

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.6275	22.5644	0.0631
	2	17.0414	17.0180	0.0234
	3	14.9285	14.9164	0.0121
2	1	22.9259	22.8534	0.0725
	2	17.0222	16.9949	0.0273
	3	15.1302	15.1187	0.0115
3	1	22.7588	22.6788	0.0800
	2	17.0284	16.9976	0.0308
	3	15.2237	15.2099	0.0138
4	1	22.8261	22.7332	0.0929
	2	17.0187	16.9891	0.0296
	3	15.2492	15.2365	0.0127
5	1	22.7028	22.6228	0.0800
	2	17.1366	17.1132	0.0234
	3	15.1280	15.1164	0.0116
6	1	22.7503	22.6496	0.1007
	2	17.1877	17.1625	0.0252
	3	15.1892	15.1769	0.0123
7	1	22.8320	22.7328	0.0992
	2	17.0632	17.0315	0.0317
	3	14.9747	14.9616	0.0131
8	1	22.7414	22.6407	0.1007
	2	17.1126	17.0863	0.0263
	3	15.2040	15.1918	0.0122

Ring No. 1 max decrease	0.1007
Ring No. 2 max decrease	0.0317
Ring No. 3 max decrease	0.0138

Ring No. 1 avg decrease	0.0861
Ring No. 2 avg decrease	0.0272
Ring No. 3 avg decrease	0.0124

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.5345	27.5214	0.0131
	Bottom	27.6127	27.5962	0.0165
2	Top	27.5403	27.5246	0.0157
	Bottom	27.5795	27.5661	0.0134
3	Top	27.5885	27.5654	0.0231
	Bottom	27.5954	27.5884	0.0070
4	Top	27.5868	27.5703	0.0165
	Bottom	27.5086	27.4981	0.0105
5	Top	27.5361	27.5225	0.0136
	Bottom	27.5505	27.5366	0.0139
6	Top	27.6061	27.5934	0.0127
	Bottom	27.5823	27.5745	0.0078
7	Top	27.5794	27.5625	0.0169
	Bottom	27.6012	27.5834	0.0178
8	Top	27.5305	27.5141	0.0164
	Bottom	27.6246	27.6081	0.0165

Maximum	0.0231
Average	0.0145

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.0311	47.9983	0.0328
	Bottom	51.5973	51.5392	0.0581
2	Top	47.9831	47.9512	0.0319
	Bottom	51.6018	51.3885	0.2133
3	Top	97.8027	96.9159	0.8868
	Bottom	103.4064	102.1396	1.2668
4	Top	47.9791	47.9432	0.0359
	Bottom	51.5222	51.4074	0.1148
5	Top	69.0665	69.0102	0.0563
	Bottom	72.7559	72.6407	0.1152

Maximum	1.2668
Average	0.2812

Stanadyne Injection Pump Calibration/Evaluation

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	SN: 15684040
Test condition :	AL:

PUMP RPM	Description	Spec.	Before	After	Change
1000	Transfer pump psi.	60-62 psi	62	62	0
	Return Fuel	225-375 cc	270	348	78
350	Low Idle	12-16 cc	16	20	4
	Housing psi.	8-12 psi	10	11	1
	Advance	3.5 deg. min	3.65	4.25	0.6
	Cold Advance Solenoid	0-1 psi.	0	0	0
750	Shut-Off	4 cc max.	0	0	0
900	Fuel Delivery	66.5 - 69.5cc	68	68	0
1600	WOT Fuel delivery	59.5 min.	66	65	1
	WOT Advance	2.5 - 3.5 deg.	2.98	3.46	0.48
	Face Cam Fuel delivery	21.5 - 23.5	22	21	1
	Face Cam Advance	5.25 - 7.25 deg.	6.41	7.2	0.79
	Low Idle	11 - 12 deg.	10.81	10.98	0.17
1825	Fuel Delivery	33 cc min.	37	54	17
1950	High Idle	15 cc max.	4	2	2
	Transfer pump psi.	125 psi max.	105	107	2
200	WOT Fuel Delivery	58 cc min.	62	62	0
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	47	47	0
	Transfer pump psi.	16 psi min.	25	30	5
	Housing psi.	0 -12 psi	9	10	1
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5	-0.5	0

*Pump calibration data to be used for reference only

PHOTOGRAPHS

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO271510	**EOT Date:**	10-31-11
Test No.:	LO271510-65T1-W-210	**Test Length:**	196

Piston Skirt Thrust - Best Cyl 7

Piston Skirt Anti-thrust - Best Cyl 7

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO271510	**EOT Date:**	10-31-11
Test No.:	LO271510-65T1-W-210	**Test Length:**	196

Piston Skirt Thrust - Worst Cyl 8

Piston Skirt Anti-thrust - Worst Cly 8

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO271510	EOT Date:	10-31-11
Test No.:	LO271510-65T1-W-210	Test Length:	196

Piston Rings - Best Cyl 1

Piston Rings - Worst Cyl 7

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO271510	**EOT Date:**	10-31-11
Test No.:	LO271510-65T1-W-210	**Test Length:**	196

Piston Undercrown - Best Cyl 7

Piston Undercrown - Worst Cyl 8

Oil Code:	LO271510	EOT Date:	10-31-11
Test No.:	LO271510-65T1-W-210	Test Length:	196

Engine Block Cylinder Bore - Best Cyl 7

Engine Block Cylinder Bore - Worst Cyl 4

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO271510	**EOT Date:**	10-31-11
Test No.:	LO271510-65T1-W-210	**Test Length:**	196

Exhaust and Intake Valve - Best Cyl 6

Oil Code:	LO271510	**EOT Date:**	10-31-11
Test No.:	LO271510-65T1-W-210	**Test Length:**	196

Exhaust and Intake Valve - Worst Cyl 4

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO271510	**EOT Date:**	10-31-11
Test No.:	LO271510-65T1-W-210	**Test Length:**	196

Rod Bearings

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO271510	**EOT Date:**	10-31-11
Test No.:	LO271510-65T1-W-210	**Test Length:**	196

Main Bearings

APPENDIX–B1
EVALUATION OF MIL-PRF-2104H
LO-257264

EVALUATION OF MIL-PRF-2104H
LO-257264

Project 14734.17

Detroit Diesel Corporation 6V53T

Test Lubricant: LO-257264
Test Fuel: Jet-A w/DCI-4A
Test Number: LO257264-6V53T1-T-240
Start of Test Date: August 25, 2011
End of Test Date: September 13, 2011
Test Duration: 240 Hours
Test Procedure: Tracked Vehicle Engine Cycle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Table of Contents

Introduction

This test was used to determine the performance of MIL-PRF-2104H (LO-257264) when used in the Detroit Diesel Corporation (DDC) 6V53T engine, by the procedures outlined in the Tracked Vehicle Engine Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.17, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the DDC 6V53T turbo-supercharged diesel engine representative of engines currently fielded in the M113 Armored Personnel Carrier (APC). Prior to testing, the engine was rebuilt using premeasured cylinder kits and rod bearings to provide a known starting condition for post test wear measurements. Engine clearances and specifications were verified, and the engine was assembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for DDC engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperature was controlled through an auxiliary fuel heater loop.

Test Procedure

The procedure outline below is followed in sequential order for each lubricant test in the DDC 6V53T engine.

- Initial Oil Flush:
  -Engine is charged with fresh test oil and a new filter (not weighed).
  -Engine operated at 1200 rpm and 88 lb-ft load until engine and oil temperatures stabilize.
  -Engine shut down and oil charge drained to remove and solvent left from engine rebuild

- Engine Run In:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is started and run-in following procedures outline in Table B1-1.
  -Immediately after run-in is complete, a no-load governor check is completed
  (2950-3030 rpm). If engine governed speed is out of spec, adjust and retest.

Table B1-1. Test Engine Run-In Procedure

Engine Speed [RPM]	Load [lb-ft]	Power (Observed) [bhp]	Duration [min]
1000	None commanded	--	10
2800	None commanded	--	30
1800	88	30	15
2200	310	130	30
2500	420	200	30
2800	422	225	30

- Engine Shake Down:
  -Engine operated for 5 hrs at 2800 rpm and 390 lb-ft load
  -After shakedown is complete, engine output is checked at max power and torque load points
  -Completed using run-in oil charge

- Pre Test Engine Powercurve:
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using run-in oil charge. Once complete, engine oil charge is drained and recorded.

- Testing:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is operated on test for 240 hrs. Test termination can be determined early due to severe piston/liner scuffing, or upon major oil degradation.
  -Oil samples collected daily for used oil analysis
  -Airbox inspections take place at 0, 60, 120, and 180 hours.

- Post Test Engine Powercurve:
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using test oil charge. Once complete, engine oil charge is drained and recorded.

Test Cycle

The test cycle followed during oil evaluation was the standard 240 hr Tracked Vehicle Engine Cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at the completion of 240 hrs. Early test termination could be called due to severe oil degradation, or upon experiencing major piston and liner scuffing during the test. The test cycle consists of cyclic modes alternating between idle, max power, and max torque load points. Total daily runtime consisted of 20 hrs of operation followed by a 4 hr engine off soak period. The cyclic mode consisted of the following modes repeated 4 times daily: 30 minutes at idle speed, 2 hours at max power, 30 minutes of idle speed, and 2 hours at max torque. Multiple engine parameters were controlled throughout testing to ensure test consistency, and are specified below in Table B1-2.

Table B1-2. Test Cycle Operating Parameters

Parameter	Max Power	Max Torque	Idle
Speed [rpm]	2800 +/- 25	1600 +/- 25	950 +/- 25
Water Jacket Out [°F]	170 +/- 5	170 +/- 5	170 +/- 5
Inlet Fuel [°F]	100 +/- 5	100 +/- 5	100 +/- 5
Oil Sump [°F]	245 +/- 5	230 +/- 5	NS (190)

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was Jet-A with the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 20 hrs for used oil analysis. Engine oil analysis consisted of the following tests outlined in Table B1-3. All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Table B1-3. Used Oil Analysis Procedures

Daily Used Oil Analysis	
ASTM D445	Kinematic Viscosity @ 100°C
ASTM D5185	Wear Metals by ICP
ASTM D4739	Total Base Number
ASTM D664	Total Acid Number

Used oil analysis results can be seen in the engine oil analysis section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred daily after the completion of the 4 hr soak prior to restarting testing. All oil additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

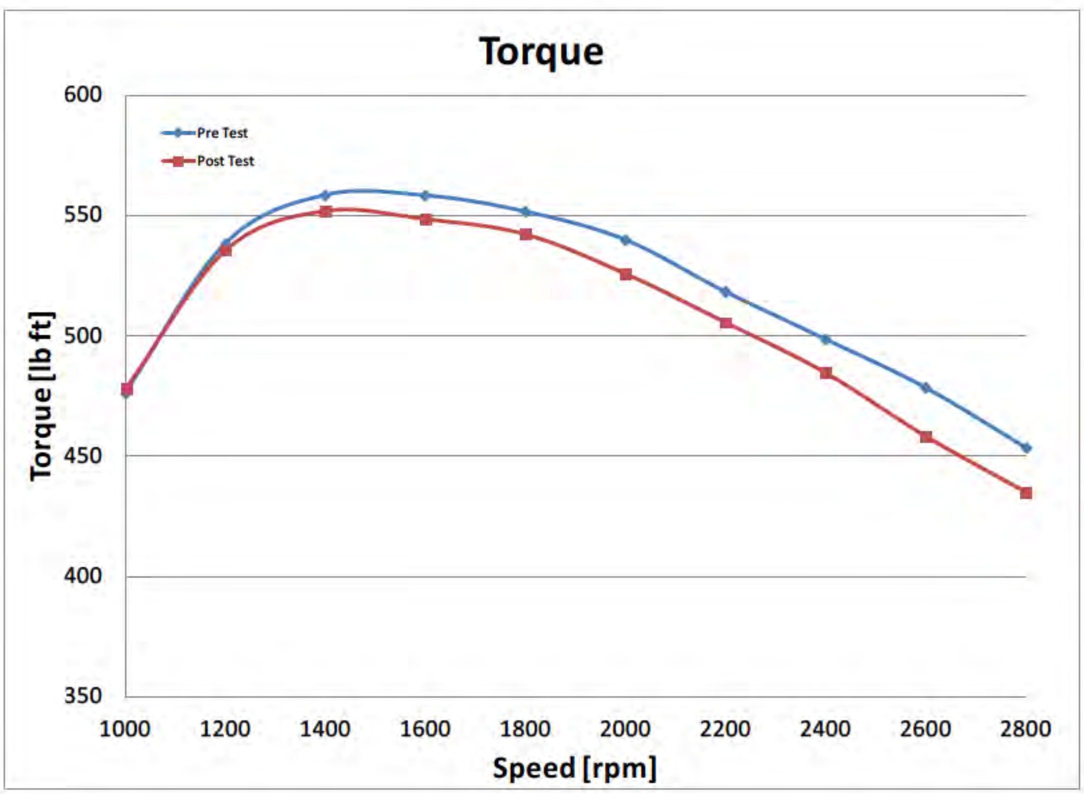
Engine Operating Conditions Summary

Below is a summary of the engine operating conditions over the test duration. The complete 240hr test schedule was completed by the lubricant.

		Peak Power (2800 RPM)		Peak Torque (1600 RPM)		Idle Conditions (950 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	2799.92	5.36	1600.00	4.76	942.87	5.60
Torque*	ft*lb	450.00	40.08	560.92	34.58	-	-
Fuel Flow	lb/hr	94.28	1.30	64.52	0.64	2.98	0.60
Power*	bhp	239.86	20.92	170.85	10.04	-	-
BSFC*	lb/bhp*hr	0.396	0.035	0.379	0.022	-	-
Engine Blowby	acfm	8.56	1.86	6.51	1.00	3.79	0.78
Relative Humidity	%	30.40	14.81	32.46	16.46	32.76	15.66
Temperatures:							
Coolant In	°F	160.61	0.88	158.74	0.93	164.81	6.41
Coolant Out	°F	170.00	0.77	170.00	0.80	167.49	6.62
Oil Galley	°F	212.51	1.43	207.66	0.82	194.12	13.05
Oil Sump	°F	245.00	0.40	230.00	0.40	197.45	13.52
Fuel In	°F	100.06	0.68	100.04	0.61	99.79	1.89
Dry Bulb	°F	95.80	7.65	94.04	8.54	92.58	7.60
Intake Air	°F	82.89	4.20	80.45	3.66	78.58	2.86
Air After Turbo	°F	296.31	6.23	210.18	4.40	86.26	3.36
Air After Supercharger	°F	279.27	4.55	201.28	3.53	143.04	10.51
Cylinder 1 Exhaust	°F	797.60	9.97	616.65	6.41	208.22	7.80
Cylinder 2 Exhaust	°F	870.37	9.93	723.30	7.13	219.11	8.44
Cylinder 3 Exhaust	°F	826.26	10.88	702.00	7.41	208.62	9.31
Cylinder 4 Exhaust	°F	794.12	10.04	646.46	8.68	186.53	6.23
Cylinder 5 Exhaust	°F	884.20	10.93	837.94	11.34	200.19	6.05
Cylinder 6 Exhaust	°F	855.70	8.83	803.17	13.50	179.17	5.96
Exhaust Exit Left	°F	896.36	8.84	871.51	9.68	196.48	4.38
Exhaust Exit Right	°F	892.39	10.71	815.79	9.71	228.93	8.24
Exhaust After Turbo	°F	689.06	8.79	686.50	9.16	220.71	18.80
Pressures:							
Oil Galley	psiG	55.15	0.54	41.86	0.54	25.49	3.53
Ambient Pressure	psiA	14.35	0.05	14.35	0.04	14.35	0.04
Pressure After Turbo	psiG	20.70	0.35	11.33	0.24	0.11	0.05
Pressure After Supercharger	psiG	22.68	0.34	10.92	0.27	0.50	0.09
Pressure Exhaust Left	psiG	19.68	0.30	10.05	0.23	0.33	0.07
Pressure Exhaust Right	psiG	18.74	0.25	9.54	0.17	0.44	0.04
Pressure Exhaust After Turbo	psiG	0.71	0.08	0.16	0.02	-0.02	0.00
Fuel Pressure	psiG	28.65	2.23	11.70	1.44	5.06	0.34

* Non-corrected Values

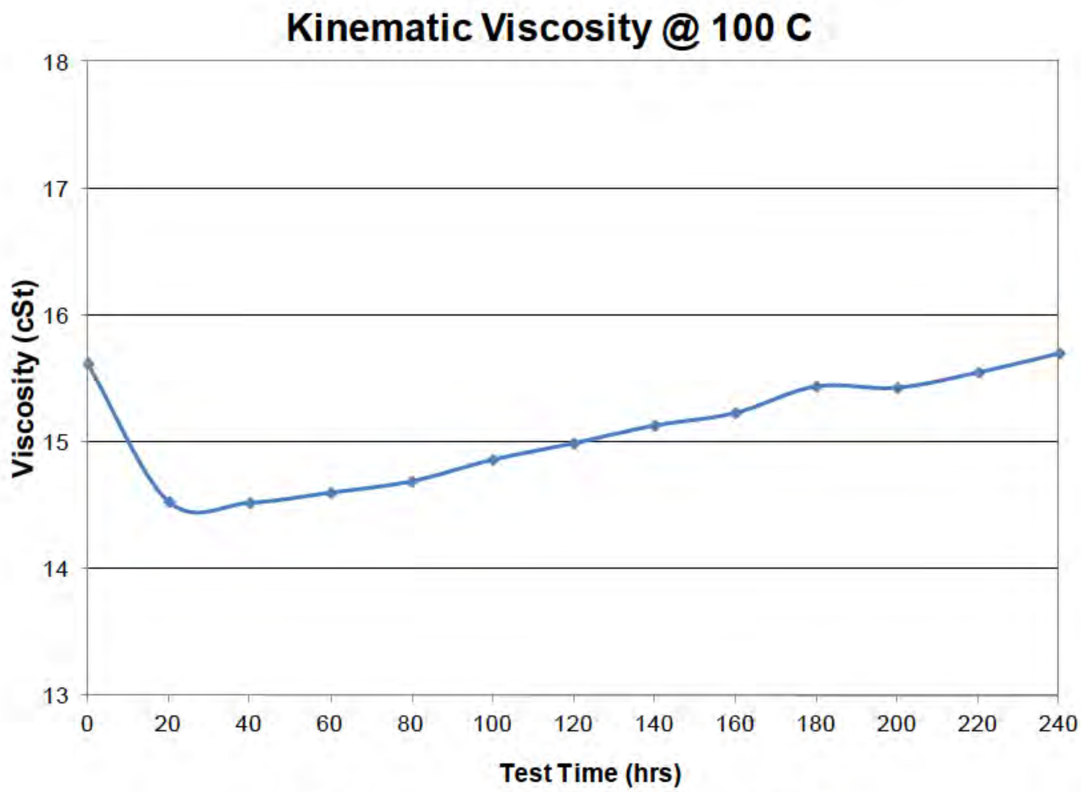
Engine Performance Curves

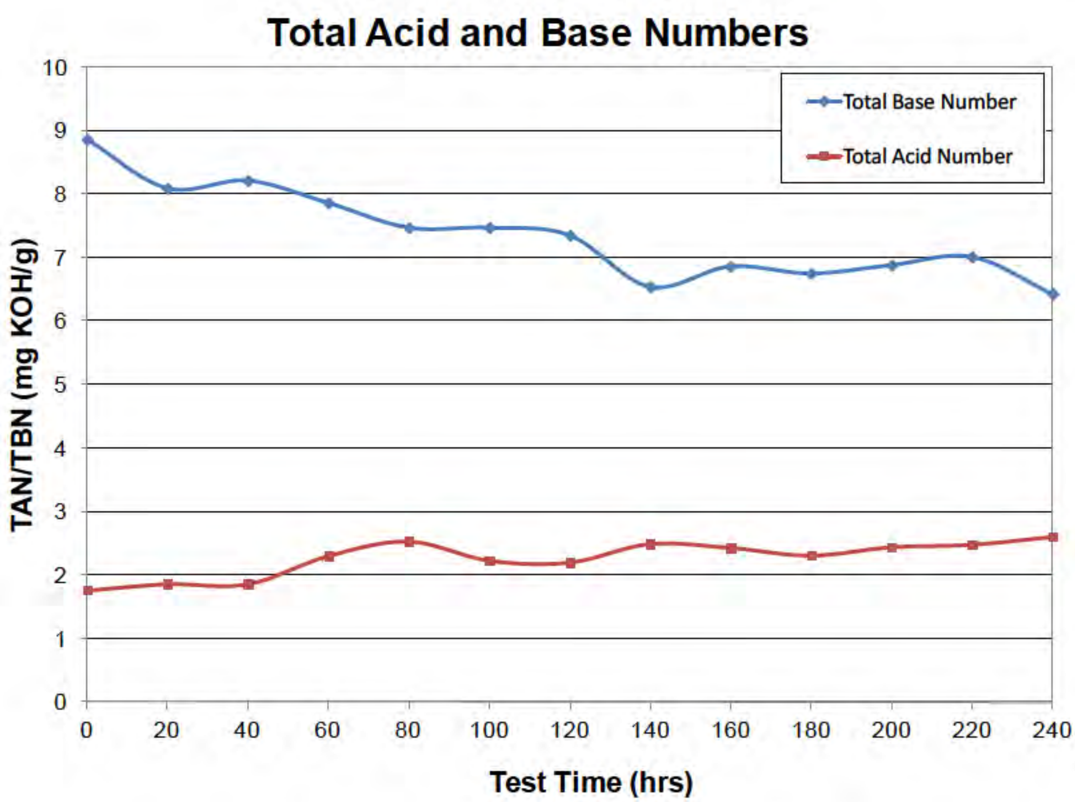


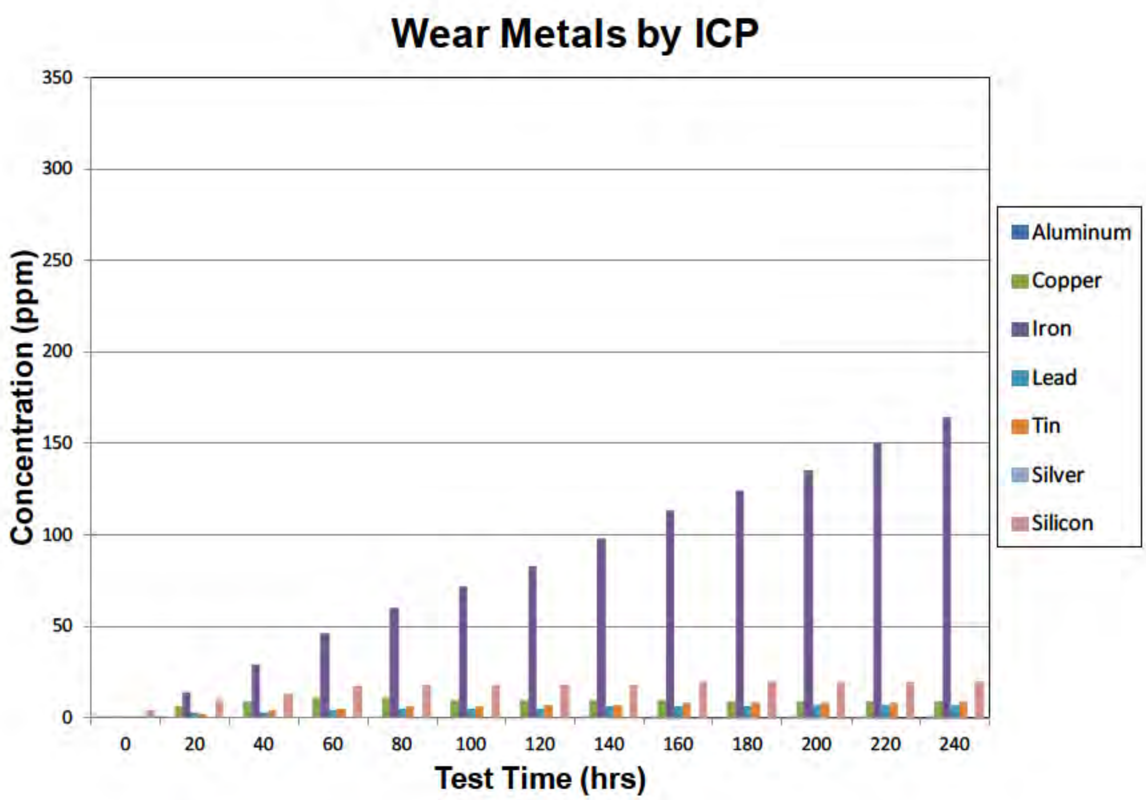
Engine Oil Analysis

Property	ASTM Test	Test Hours												
		0	20	40	60	80	100	120	140	160	180	200	220	240
Viscosity @ 100°C (cSt)	D445	15.6	14.5	14.5	14.6	14.7	14.9	15.0	15.1	15.2	15.4	15.4	15.6	15.7
Total Base Number (mg KOH/g)	D4739	8.9	8.1	8.2	7.9	7.5	7.5	7.4	6.5	6.9	6.8	6.9	7.0	6.4
Total Acid Number (mg KOH/g)	D664	1.8	1.9	1.9	2.3	2.5	2.2	2.2	2.5	2.4	2.3	2.4	2.5	2.6
Wear Metals (ppm)	D5185													
Al		<1	<1	<1	<1	1	<1	<1	1	1	<1	1	1	1
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		3	1	2	2	2	2	2	2	<1	2	2	2	2
Ca		2290	2407	2446	2472	2544	2586	2569	2693	2570	2621	2676	2761	2722
Cr		<1	<1	<1	1	2	2	2	3	3	3	3	3	4
Cu		<1	6	9	11	11	10	10	10	10	9	9	9	9
Fe		1	14	29	46	60	72	83	98	113	124	135	150	164
Pb		<1	3	3	4	5	5	5	6	6	6	7	7	7
Mg		271	280	286	300	302	309	301	321	306	307	311	320	318
Mn		<1	<1	<1	<1	1	1	1	2	2	2	2	2	2
Mo		1	2	3	4	5	6	6	7	8	8	9	10	10
Ni		<1	<1	<1	<1	<1	<1	<1	<1	1	1	1	1	2
P		1177	1171	1149	1122	1151	1162	1136	1168	1128	1109	1148	1161	1131
Si		4	10	13	17	18	18	18	18	20	20	19	19	20
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		<5	<5	<5	5	<5	5	<5	7	<5	<5	5	6	<5
Sn		<1	2	4	5	6	6	7	7	8	8	8	8	9
Zn		1379	1398	1363	1375	1435	1412	1423	1448	1463	1452	1461	1472	1477
K		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sr		1	1	<1	1	<1	<1	<1	<1	2	<1	<1	<1	1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Engine Oil Analysis Trends







Wear Metals by ICP
Concentration (ppm)
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
220
240
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

Oil Consumption Data

Average oil consumption per test hour was 0.249 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
20 hr	4.6	0.23	4.37	4.37
40 hr	6.3	0.22	6.08	10.45
60 hr	7	0.22	6.78	17.23
80 hr	7.15	0.23	6.92	24.15
100 hr	5.51	0.22	5.29	29.44
120 hr	5.25	0.22	5.03	34.47
140 hr	3.48	0.22	3.26	37.73
160 hr	4.86	0.23	4.63	42.36
180 hr	5.63	0.24	5.39	47.75
200 hr	3.5	0.23	3.27	51.02
220 hr	2.34	0.23	2.11	53.13
240 hr	6.75	0.24	6.51	59.64
	Initial Fill	37.5	**Total Additions**	62.37
	EOT Drain	37.44	**Total Samples**	2.73

(Initial Fill + Additions)	99.87
(EOT Drain + Samples)	40.17
Total Oil Consumption	59.7

Engine Measurements

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA	Out of Round
1L	13mm From Top	3.8761	3.8764		0.0003
	25mm Above Port	3.8760	3.8764	3.8762	0.0004
	25mm Below Port	3.8759	3.8762		0.0003
	13mm From Bottom	3.8764	3.8762		0.0002
	Taper	0.0005	0.0002		
2L	13mm From Top	3.8765	3.8762		0.0003
	25mm Above Port	3.8764	3.8763	3.8763	0.0001
	25mm Below Port	3.8762	3.8760		0.0002
	13mm From Bottom	3.8764	3.8763		0.0001
	Taper	0.0003	0.0003		
3L	13mm From Top	3.8764	3.8760		0.0004
	25mm Above Port	3.8764	3.8762	3.8763	0.0002
	25mm Below Port	3.8761	3.8760		0.0001
	13mm From Bottom	3.8767	3.8762		0.0005
	Taper	0.0006	0.0002		
1R	13mm From Top	3.8760	3.8763		0.0003
	25mm Above Port	3.8762	3.8761	3.8761	0.0001
	25mm Below Port	3.8759	3.8759		0.0000
	13mm From Bottom	3.8763	3.8761		0.0002
	Taper	0.0004	0.0004		
2R	13mm From Top	3.8766	3.8761		0.0005
	25mm Above Port	3.8764	3.8761	3.8763	0.0003
	25mm Below Port	3.8762	3.8760		0.0002
	13mm From Bottom	3.8765	3.8765		0.0000
	Taper	0.0004	0.0005		
3R	13mm From Top	3.8762	3.8764		0.0002
	25mm Above Port	3.8762	3.8763	3.8763	0.0001
	25mm Below Port	3.8760	3.8761		0.0001
	13mm From Bottom	3.8765	3.8766		0.0001
	Taper	0.0005	0.0005		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA	Out of Round
1L	13mm From Top	3.8769	3.8762		0.0007
	25mm Above Port	3.8763	3.8763	3.8763	0.0000
	25mm Below Port	3.8761	3.8763		0.0002
	13mm From Bottom	3.8761	3.8763		0.0002
	Taper	0.0008	0.0001		
2L	13mm From Top	3.8767	3.8765		0.0002
	25mm Above Port	3.8765	3.8763	3.8764	0.0002
	25mm Below Port	3.8764	3.8761		0.0003
	13mm From Bottom	3.8763	3.8765		0.0002
	Taper	0.0004	0.0004		
3L	13mm From Top	3.8770	3.8762		0.0008
	25mm Above Port	3.8764	3.8762	3.8764	0.0002
	25mm Below Port	3.8762	3.8761		0.0001
	13mm From Bottom	3.8764	3.8764		0.0000
	Taper	0.0008	0.0003		
1R	13mm From Top	3.8766	3.8764		0.0002
	25mm Above Port	3.8764	3.8764	3.8764	0.0000
	25mm Below Port	3.8761	3.8763		0.0002
	13mm From Bottom	3.8761	3.8766		0.0005
	Taper	0.0005	0.0003		
2R	13mm From Top	3.8772	3.8762		0.0010
	25mm Above Port	3.8768	3.8765	3.8766	0.0003
	25mm Below Port	3.8766	3.8762		0.0004
	13mm From Bottom	3.8765	3.8769		0.0004
	Taper	0.0007	0.0007		
3R	13mm From Top	3.8767	3.8762		0.0005
	25mm Above Port	3.8764	3.8761	3.8764	0.0003
	25mm Below Port	3.8764	3.8760		0.0004
	13mm From Bottom	3.8762	3.8769		0.0007
	Taper	0.0005	0.0009		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA Change	Out of Round
1L	13mm From Top	0.0008	0.0002		0.0004
	25mm Above Port	0.0003	0.0001	0.0003	0.0004
	25mm Below Port	0.0002	0.0001		0.0001
	13mm From Bottom	0.0003	0.0001		0.0000
	Taper	0.0006	0.0001		
2L	13mm From Top	0.0002	0.0003		0.0001
	25mm Above Port	0.0001	0.0000	0.0002	0.0001
	25mm Below Port	0.0002	0.0001		0.0001
	13mm From Bottom	0.0001	0.0002		0.0001
	Taper	0.0001	0.0003		
3L	13mm From Top	0.0006	0.0002		0.0004
	25mm Above Port	0.0000	0.0000	0.0002	0.0000
	25mm Below Port	0.0001	0.0001		0.0000
	13mm From Bottom	0.0003	0.0002		0.0005
	Taper	0.0006	0.0002		
1R	13mm From Top	0.0006	0.0001		0.0001
	25mm Above Port	0.0002	0.0003	0.0003	0.0001
	25mm Below Port	0.0002	0.0004		0.0002
	13mm From Bottom	0.0002	0.0005		0.0003
	Taper	0.0004	0.0004		
2R	13mm From Top	0.0006	0.0001		0.0005
	25mm Above Port	0.0004	0.0004	0.0003	0.0000
	25mm Below Port	0.0004	0.0002		0.0002
	13mm From Bottom	0.0000	0.0004		0.0004
	Taper	0.0006	0.0003		
3R	13mm From Top	0.0005	0.0002		0.0003
	25mm Above Port	0.0002	0.0002	0.0003	0.0002
	25mm Below Port	0.0004	0.0001		0.0003
	13mm From Bottom	0.0003	0.0003		0.0006
	Taper	0.0003	0.0002		
Avgerage All Cylinders	13mm From Top	0.0006	0.0002		
	25mm Above Port	0.0002	0.0002		
	25mm Below Port	0.0002	0.0002		
	13mm From Bottom	0.0002	0.0003		

Pre-Test Liner Surface Finish, µm

Pre Test Liner Surface Finish, µm					
1L	2L	3L	1R	2R	3R
1.31	1.38	1.48	1.32	1.41	1.43

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	3.8762	3.8705	0.0058
	2	3.8763	3.8703	0.0060
	3	3.8763	3.8704	0.0059
	4	3.8761	3.8704	0.0058
	5	3.8763	3.8704	0.0059
	6	3.8763	3.8704	0.0059
Post - Test	1	3.8763	3.8704	0.0059
	2	3.8764	3.8694	0.0071
	3	3.8764	3.8691	0.0073
	4	3.8764	3.8696	0.0068
	5	3.8766	3.8702	0.0064
	6	3.8764	3.8694	0.0070

Connecting Rod Bearing Mass Change, grams

Rod Bearing	Shell	Before	After	Change
1L	Top	73.6495	73.6297	0.0198
	Bottom	67.8243	67.8210	0.0033
2L	Top	73.4362	73.4133	0.0229
	Bottom	67.7831	67.7786	0.0045
3L	Top	73.4769	73.4644	0.0125
	Bottom	67.8587	67.8555	0.0032
1R	Top	73.4915	73.4771	0.0144
	Bottom	68.3085	68.3036	0.0049
2R	Top	73.4822	73.4681	0.0141
	Bottom	68.1717	68.1779	-0.0062
3R	Top	73.2623	73.2486	0.0137
	Bottom	69.3699	69.3658	0.0041

Maximum	0.0229
Average	0.0093

Slipper Bushing Mass Change, grams

Slipper Bushing	Before	After	Change
1L	56.2768	56.2085	0.0683
2L	55.9443	55.8420	0.1023
3L	56.2014	56.0414	0.1600
1R	56.0874	56.0086	0.0788
2R	56.2125	56.1151	0.0974
3R	56.1273	55.9975	0.1298

Maximum	0.1600
Average	0.1061

Pre-Test Slipper Bushing Tin Plate Thickness, inches

Slipper Bushing Tin Plate Thickness					
1L	2L	3L	1R	2R	3R
0.02370	0.02300	0.02310	0.02330	0.02385	0.02310

Top, Second, and Third Ring Radial Measurements, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1L	1	0.15950	0.15870	0.00080
	2	0.15895	0.15875	0.00020
	3	0.16040	0.16005	0.00035
	4	0.16025	0.16020	0.00005
	5	0.15895	0.15820	0.00075
2L	1	0.15590	0.15510	0.00080
	2	0.15550	0.15520	0.00030
	3	0.15590	0.15570	0.00020
	4	0.15570	0.15550	0.00020
	5	0.15690	0.15600	0.00090
3L	1	0.15680	0.15600	0.00080
	2	0.15630	0.15590	0.00040
	3	0.15905	0.15860	0.00045
	4	0.15905	0.15865	0.00040
	5	0.15765	0.15655	0.00110
1R	1	0.15630	0.15505	0.00125
	2	0.15570	0.15570	0.00000
	3	0.15625	0.15590	0.00035
	4	0.15655	0.15620	0.00035
	5	0.15775	0.15615	0.00160
2R	1	0.15655	0.15560	0.00095
	2	0.15660	0.15635	0.00025
	3	0.15685	0.15625	0.00060
	4	0.15675	0.15640	0.00035
	5	0.15690	0.15590	0.00100
3R	1	0.15555	0.15505	0.00050
	2	0.15570	0.15555	0.00015
	3	0.15655	0.15645	0.00010
	4	0.15570	0.15545	0.00025
	5	0.15590	0.15535	0.00055

*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error

Maximum	0.00160
Average	0.00053

Second Ring				
Cylinder	Position	Before	After	Delta
1L	1	0.14860	0.14765	0.00095
	2	0.14815	0.14740	0.00075
	3	0.14840	0.14720	0.00120
	4	0.14895	0.14780	0.00115
	5	0.14880	0.14780	0.00100
2L	1	0.14590	0.14500	0.00090
	2	0.14690	0.14650	0.00040
	3	0.14705	0.14650	0.00055
	4	0.14620	0.14565	0.00055
	5	0.14540	0.14480	0.00060
3L	1	0.14730	0.14655	0.00075
	2	0.14750	0.14715	0.00035
	3	0.17640	0.17570	0.00070
	4	0.14715	0.14675	0.00040
	5	0.14735	0.14670	0.00065
1R	1	0.14710	0.14610	0.00100
	2	0.14785	0.14720	0.00065
	3	0.14670	0.14605	0.00065
	4	0.14620	0.14550	0.00070
	5	0.14690	0.14610	0.00080
2R	1	0.14680	0.14600	0.00080
	2	0.14720	0.14660	0.00060
	3	0.14775	0.14700	0.00075
	4	0.14895	0.14815	0.00080
	5	0.14810	0.14750	0.00060
3R	1	0.14770	0.14720	0.00050
	2	0.14815	0.14755	0.00060
	3	0.14890	0.14635	0.00255
	4	0.14625	0.14590	0.00035
	5	0.14685	0.14635	0.00050

*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error

Maximum	0.00255
Average	0.00076

Third Ring				
Cylinder	Position	Before	After	Delta
1L	1	0.14865	0.14805	0.00060
	2	0.14950	0.14905	0.00045
	3	0.14810	0.14725	0.00085
	4	0.14820	0.14745	0.00075
	5	0.14830	0.14765	0.00065
2L	1	0.14655	0.14630	0.00025
	2	0.14560	0.14540	0.00020
	3	0.14625	0.14610	0.00015
	4	0.14710	0.14695	0.00015
	5	0.14675	0.14635	0.00040
3L	1	0.14730	0.14690	0.00040
	2	0.14720	0.14690	0.00030
	3	0.14620	0.14575	0.00045
	4	0.14675	0.14660	0.00015
	5	0.14725	0.14685	0.00040
1R	1	0.14655	0.14620	0.00035
	2	0.14790	0.14765	0.00025
	3	0.14680	0.14655	0.00025
	4	0.14615	0.14580	0.00035
	5	0.14655	0.14560	0.00095
2R	1	0.14735	0.14705	0.00030
	2	0.14885	0.14855	0.00030
	3	0.14855	0.14825	0.00030
	4	0.14750	0.14720	0.00030
	5	0.14720	0.14685	0.00035
3R	1	0.14800	0.14785	0.00015
	2	0.14675	0.14640	0.00035
	3	0.14680	0.14650	0.00030
	4	0.14820	0.14800	0.00020
	5	0.14800	0.14775	0.00025

*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error

Maximum	0.00095
Average	0.00037

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Increase
1L	1	0.035	0.045	0.010
	2	0.025	0.038	0.013
	3	0.025	0.035	0.010
	4	0.015	0.026	0.011
	5a	0.013	0.021	0.008
	5b	0.013	0.021	0.008
2L	1	0.029	0.035	0.006
	2	0.027	0.035	0.008
	3	0.024	0.033	0.009
	4	0.015	0.024	0.009
	5a	0.013	0.020	0.007
	5b	0.013	0.021	0.008
3L	1	0.033	0.035	0.002
	2	0.025	0.033	0.008
	3	0.026	0.034	0.008
	4	0.014	0.022	0.008
	5a	0.013	0.020	0.007
	5b	0.013	0.020	0.007
1R	1	0.028	0.035	0.007
	2	0.026	0.035	0.009
	3	0.026	0.035	0.009
	4	0.013	0.021	0.008
	5a	0.015	0.021	0.006
	5b	0.015	0.021	0.006
2R	1	0.033	0.035	0.002
	2	0.027	0.035	0.008
	3	0.028	0.035	0.007
	4	0.013	0.023	0.010
	5a	0.014	0.022	0.008
	5b	0.013	0.022	0.009
3R	1	0.032	0.033	0.001
	2	0.026	0.033	0.007
	3	0.027	0.034	0.007
	4	0.010	0.021	0.011
	5a	0.013	0.022	0.009
	5b	0.013	0.022	0.009

Ring No. 1 max increase	0.010
Ring No. 2 max increase	0.013
Ring No. 3 max increase	0.010
Ring No. 4 max increase	0.011
Ring No. 5a max increase	0.009
Ring No. 5b max increase	0.009

Ring No. 1 avg increase	0.005
Ring No. 2 avg increase	0.009
Ring No. 3 avg increase	0.008
Ring No. 4 avg increase	0.010
Ring No. 5a avg increase	0.008
Ring No. 5b avg increase	0.008

Piston Ring Mass Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1L	1	23.5815	23.5670	0.0145
	2	20.3114	20.1974	0.1140
	3	20.2918	20.2317	0.0601
	4	27.4618	27.4449	0.0169
	5	24.6281	24.6040	0.0241
2L	1	22.9939	22.9750	0.0189
	2	20.0646	20.0242	0.0404
	3	20.0661	20.0536	0.0125
	4	27.8223	27.8044	0.0179
	5	24.0037	23.9860	0.0177
3L	1	23.2390	23.2242	0.0148
	2	20.1780	20.1311	0.0469
	3	20.1394	20.1197	0.0197
	4	27.5357	27.5178	0.0179
	5	24.3062	24.2876	0.0186
1R	1	23.0231	23.0120	0.0111
	2	20.1552	20.0835	0.0717
	3	20.1442	20.1114	0.0328
	4	27.5512	27.5310	0.0202
	5	24.2948	24.2740	0.0208
2R	1	23.1091	23.0938	0.0153
	2	20.2545	20.2006	0.0539
	3	20.3200	20.3009	0.0191
	4	27.3550	27.3399	0.0151
	5	24.3167	24.2977	0.0190
3R	1	23.0662	23.0567	0.0095
	2	20.1822	20.1419	0.0403
	3	20.2256	20.2146	0.0110
	4	27.3387	27.3213	0.0174
	5	24.4991	24.4795	0.0196

Ring No. 1 max decrease	0.0189
Ring No. 2 max decrease	0.1140
Ring No. 3 max decrease	0.0601
Ring No. 4 max decrease	0.0202
Ring No. 5 max decrease	0.0241

Ring No. 1 avg decrease	0.0140
Ring No. 2 avg decrease	0.0612
Ring No. 3 avg decrease	0.0259
Ring No. 4 avg decrease	0.0176
Ring No. 5 avg decrease	0.0200

Oil Control & Expander Ring Tension, pounds

	Oil Control & Expander Ring Tension					
	1L	2L	3L	1R	2R	3R
Top Oil Ring	7.7	8.3	7.5	10.7	7.7	7.7
Second Oil Ring	7.5	7.4	7.3	10.2	8	8.3

NOTE – To be used as reference only.
Measurements taken with non-calibrated legacy equipment.

Post Test Engine Ratings

Piston Ratings, Demerits

Ratings	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Avg
Ring Sticking (F=Free, CS=Cold Stuck, HS=Hot Stuck, CP=Collapsed Ring, No. Denotes % Of Ring Circumference)							
Top	F	F	F	F	F	F	--
Second	25% CS	F	40% CS	10% CS	95% CS	90% CS	--
Third	F	F	F	F	F	F	--
Oil Control Rings	F	F	F	F	F	F	--
2nd Ring Carbon							
Heavy Carbon	26	33	93	70	76	53	--
Light Carbon	74	67	7	30	20	37	--
Piston Carbon, Demerits							
No.1 Groove	59.50	65.25	74.50	61.75	60.50	40.50	60.33
No.2 Groove	38.50	43.75	35.50	32.50	27.25	29.75	34.54
No.3 Groove	25.00	25.00	25.00	25.00	23.25	23.50	24.46
No.1 Land	35.50	45.25	41.00	48.50	30.50	40.75	40.25
No.2 Land	55.00	64.00	51.00	60.25	61.75	50.50	57.08
No.3 Land	20.00	0.00	13.25	10.75	9.00	10.50	10.58
No.4 Land	6.75	11.25	10.00	6.00	2.75	4.50	6.88
Piston Lacquer, Demerits							
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	0.00	0.00	0.00	0.00	0.00	0.06	0.01
No.3 Groove	0.00	0.00	0.00	0.00	0.21	0.27	0.08
No.1 Land	0.27	0.00	0.37	0.18	0.18	0.54	0.26
No.2 Land	0.00	0.00	0.09	0.00	0.16	0.27	0.09
No.3 Land	0.72	0.65	1.92	2.30	2.94	3.07	1.93
No.4 Land	2.25	1.90	1.89	2.25	3.66	3.03	2.50
Total, Demerits	243.49	257.05	254.52	249.48	222.15	207.24	238.99
Miscellanous							
Top Groove Fill, %	60	65	75	71	46	40	59.50
Intermediate Groove Fill, %	73	70	64	57	50	49	60.50
Top Land Heavy Carbon, %	15	27	23	32	8	23	21.33
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0.00

Ring Face Distress, Demerits

Cylinder No.	Ring No.	Extreme Distress (1.00) % Area	Heavy Distress (0.75) % Area	Medium Distress (0.50) % Area	Light Distress (0.25) % Area	No Distress (0.00) % Area	Total Demerits
1L	1				17	83	0.0425
	2						0
	3						0
2L	1			1	4	95	0.015
	2						0
	3						0
3L	1				10	90	0.025
	2						0
	3						0
1R	1		3	1	14	82	0.0625
	2						0
	3						0
2R	1				8	92	0.02
	2						0
	3						0
3R	1				3	97	0.0075
	2						0
	3						0

Piston Ring Face Distress	Fire Ring	2nd Ring	3rd Ring
Average Demerits	0.0288	0.0000	0.0000

EOT Cylinder Liner Ratings, % Area

	Cylinder Liner Ratings					
	% Scuffing		Total % Area Scuffed	% Polish		Total % Area Polished
	T	AT		T	AT	
1L	0	0	0	8	3	11
2L	0	0	0	0	10	10
3L	0	0	0	7	4	11
1R	0	0	0	2	4	6
2R	0	0	0	3	5	8
3R	0	0	0	6	4	10
Percent of total ring travel area						

Periodic Bore Inspection Results, % Area

Periodic Bore Inspection, % Scuffed Area				
Cyl	**0hr**	**60hr**	**120hr**	**180hr**
1L	0	0	0	0
2L	0	0	0	0
3L	0	0	0	0
1R	0	0	0	0
2R	0	0	0	0
3R	0	0	0	0

Piston Skirt Ratings

	Piston Skirt Ratings	
	Thrust	Anti-Thrust
1L	Few Light Scratches, 1% Scuffing	Few Light Scratches, 2% Scuffing
2L	Few Light Scratches	Few Light Scratches
3L	Few Light Scratches	Few Light Scratches
1R	Few Light Scratches	Few Light Scratches
2R	Few Light Scratches	Few Light Scratches
3R	Numerous Light Scratches	Few Light Scratches

EOT Intake Port Plugging & Slipper Bushing Exposed Copper, %

Intake Port Plugging	
1L	2.5
2L	2
3L	3
1R	0.5
2R	1
3R	25.5
Average	5.75

Slipper Bushing % Exposed Copper	
1L	2
2L	15
3L	10
1R	6
2R	8
3R	12
Average	8.83

PHOTOGRAPHS

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	**EOT Date:**	9/13/11
Test No.:	LO257264-6V53T2-T-240	**Test Length:**	240

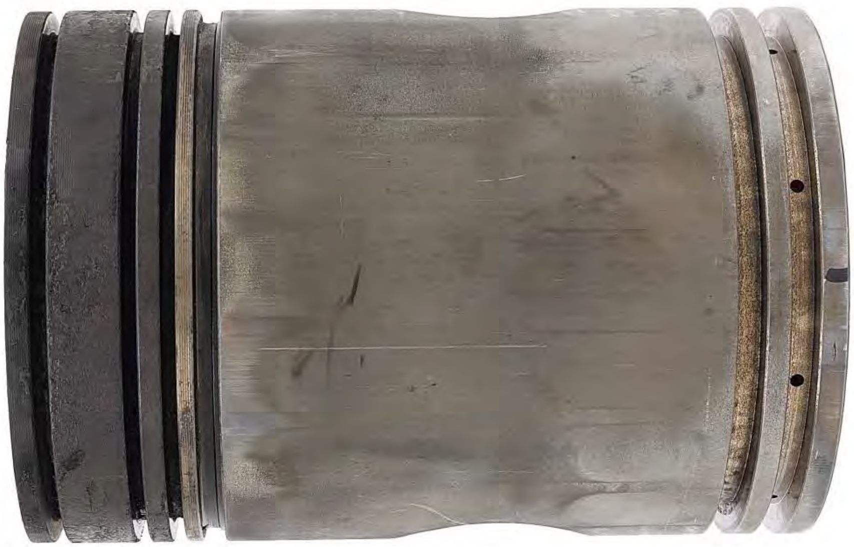
Ring Pack 1 Left

Ring Pack 1 Right

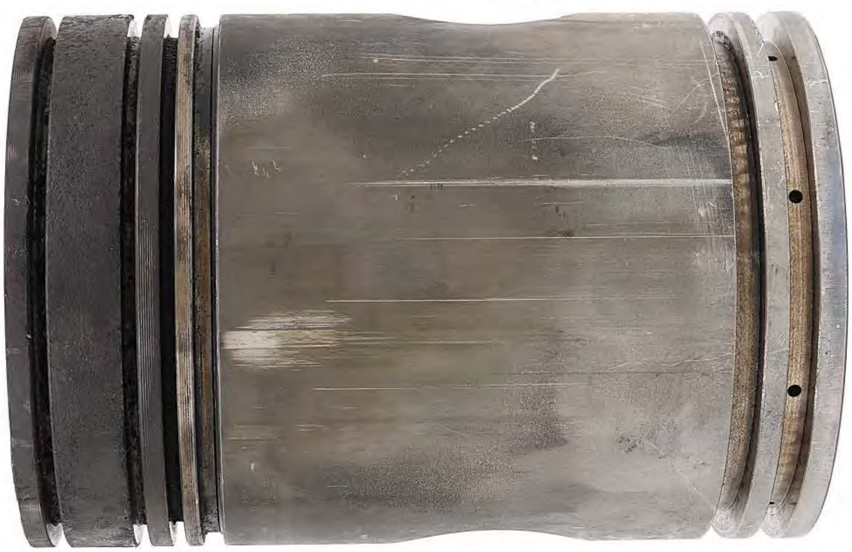
DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

Piston 1 Left Thrust



Piston 1 Left Anti-thrust

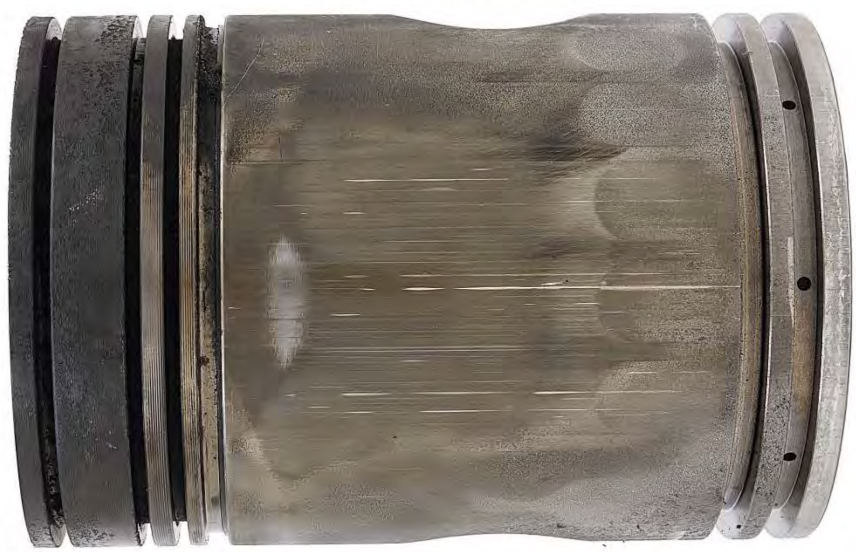


DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	**EOT Date:**	9/13/11
Test No.:	LO257264-6V53T2-T-240	**Test Length:**	240

Piston 1 Right Thrust

Piston 1 Right Anti-thrust



Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

Liner 1 Left Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

Liner 1 Right Thrust and Anti-thrust

Oil Code:	LO257264	**EOT Date:**	9/13/11
Test No.:	LO257264-6V53T2-T-240	**Test Length:**	240

Ring Pack 2 Left

Ring Pack 2 Right

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	**EOT Date:**	9/13/11
Test No.:	LO257264-6V53T2-T-240	**Test Length:**	240

Piston 2 Left Thrust

Piston 2 Left Anti-thrust

Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

Piston 2 Right Thrust

Piston 2 Right Anti-thrust

Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

Liner 2 Left Thrust and Anti-thrust

Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

Liner 2 Right Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

Ring Pack 3 Left

Ring Pack 3 Right

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

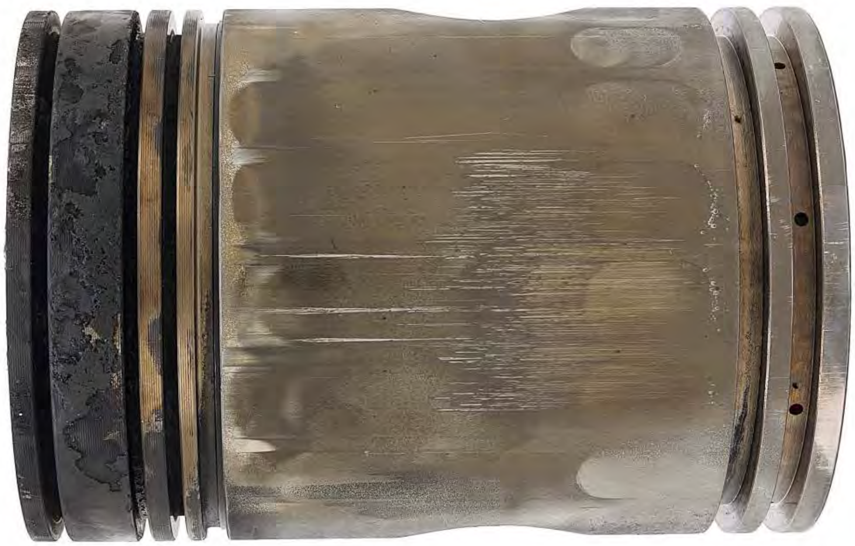
Piston 3 Left Thrust

Piston 3 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

Piston 3 Right Thrust



Piston 3 Right Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

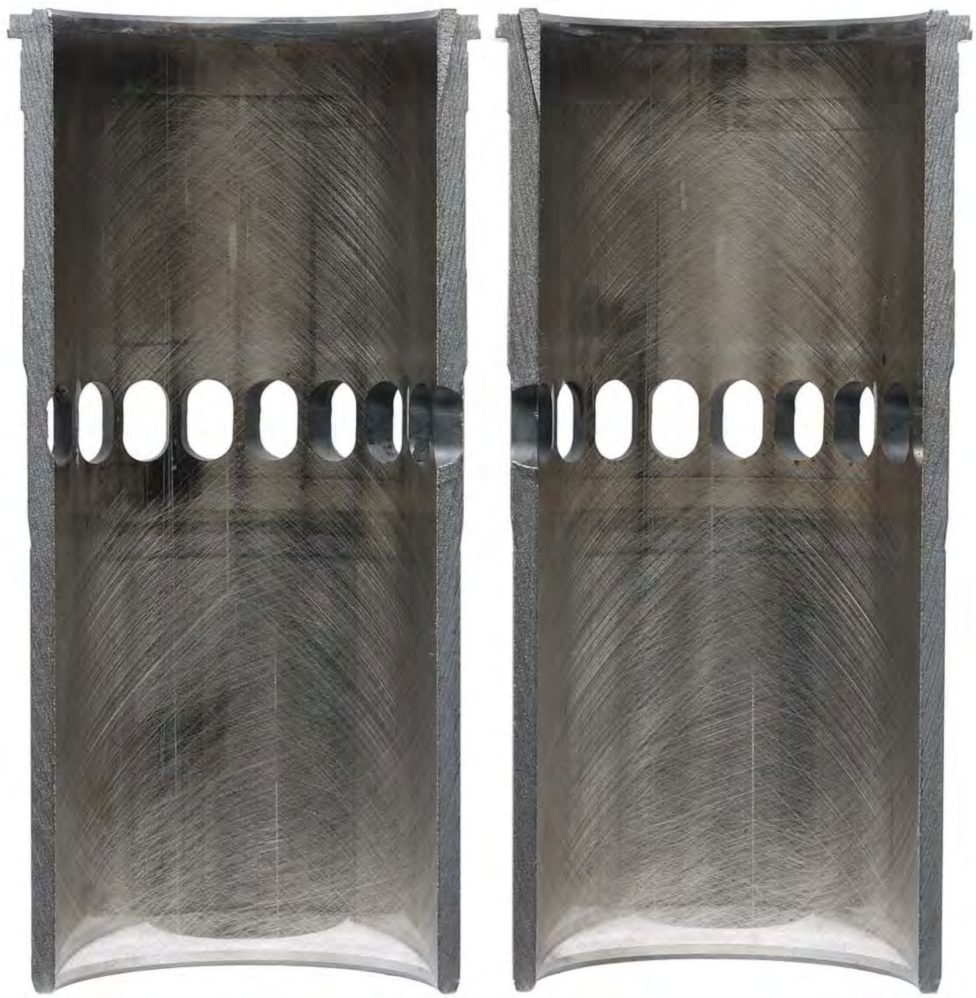
Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

Liner 3 Left Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	EOT Date:	9/13/11
Test No.:	LO257264-6V53T2-T-240	Test Length:	240

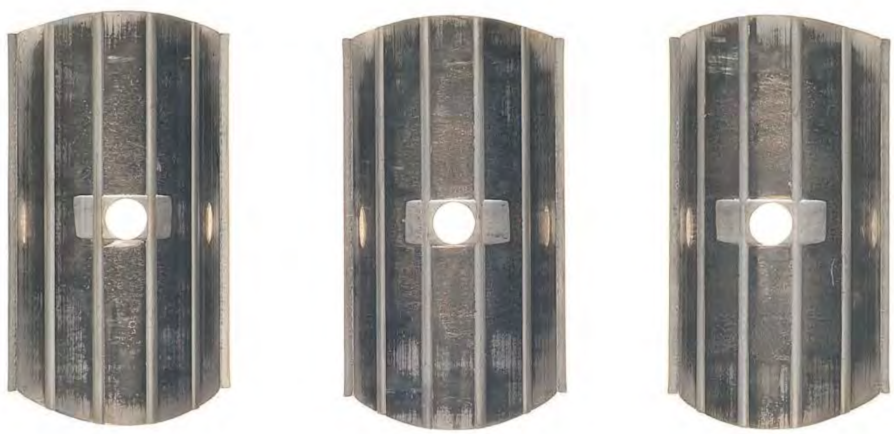
Liner 3 Right Thrust and Anti-thrust



DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	**EOT Date:**	9/13/11
Test No.:	LO257264-6V53T2-T-240	**Test Length:**	240

Slipper Bushings 1R, 2R, 3R



Slipper Bushings 1L, 2L, 3L

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO257264	**EOT Date:**	9/13/11
Test No.:	LO257264-6V53T2-T-240	**Test Length:**	240

Connecting Rod Bearings

Upper 1L, 2L, 3L, 1R, 2R, 3R **Lower 1L, 2L, 3L, 1R, 2R, 3R**

APPENDIX – B2
EVALUATION OF SCPL CANDIDATE
LO-268869

EVALUATION OF SCPL CANDIDATE LO-268869

Project 14734.17

Detroit Diesel Corporation 6V53T

Test Lubricant: LO-268869
Test Fuel: Jet-A w/DCI-4A
Test Number: LO268869-6V53T1-T-240
Start of Test Date: October 11, 2011
End of Test Date: October 27, 2011
Test Duration: 240 Hours
Test Procedure: Tracked Vehicle Engine Cycle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Table of Contents

Introduction

This test was used to determine the performance of SCPL candidate LO268869 when used in the Detroit Diesel Corporation (DDC) 6V53T engine, by the procedures outlined in the Tracked Vehicle Engine Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.17, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the DDC 6V53T turbo-supercharged diesel engine representative of engines currently fielded in the M113 Armored Personnel Carrier (APC). Prior to testing, the engine was rebuilt using premeasured cylinder kits and rod bearings to provide a known starting condition for post test wear measurements. Engine clearances and specifications were verified, and the engine was assembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for DDC engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperature was controlled through an auxiliary fuel heater loop.

Test Procedure

The procedure outline below is followed in sequential order for each lubricant test in the DDC 6V53T engine.

- Initial Oil Flush:
  -Engine is charged with fresh test oil and a new filter (not weighed).
  -Engine operated at 1200 rpm and 88 lb-ft load until engine and oil temperatures stabilize.
  -Engine shut down and oil charge drained to remove and solvent left from engine rebuild

- Engine Run In:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is started and run-in following procedures outline below.
  -Immediately after run-in is complete, a no-load governor check is completed (2950-3030rpm). If engine governed speed is out of spec, adjust and retest.

Table 1 - Test Engine Run-In Procedure

Engine Speed [RPM]	Load [lb-ft]	Power (Observed) [bhp]	Duration [min]
1000	None commanded	--	10
2800	None commanded	--	30
1800	88	30	15
2200	310	130	30
2500	420	200	30
2800	422	225	30

- Engine Shake Down:
  -Engine operated for 5hrs at 2800 rpm and 390 lb-ft load
  -After shakedown is complete, engine output is checked at max power and torque load points
  -Completed using run-in oil charge

- Pre Test Engine Powercurve:
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using run-in oil charge. Once complete, engine oil charge is drained and recorded.

- Testing:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is operated on test for 240hrs. Test termination can be determined early due to severe piston/liner scuffing, or upon major oil degradation.
  -Oil samples collected daily for used oil analysis
  -Airbox inspections take place at 0, 60, 120, and 180 hours.

- Post Test Engine Powercurve:
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using test oil charge. Once complete, engine oil charge is drained and recorded.

Test Cycle

The test cycle followed during oil evaluation was the standard 240 hr Tracked Vehicle Engine Cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at the completion of 240 hrs. Early test termination could be called due to severe oil degradation, or upon experiencing major piston and liner scuffing during the test. The test cycle consists of cyclic modes alternating between idle, max power, and max torque load points. Total daily runtime consisted of 20hrs of operation followed by a 4hr engine off soak period. The cyclic mode consisted of the following modes repeated 4 times daily: 30 minutes at idle speed, 2 hours at max power, 30 minutes of idle speed, 2 hours at max torque. Multiple engine parameters were controlled throughout testing to ensure test consistency, and are specified below in Table 2.

Table 2 - Test Cycle Operating Parameters

Parameter	Max Power	Max Torque	Idle
Speed [rpm]	2800 +/- 25	1600 +/- 25	950 +/- 25
Water Jacket Out [°F]	170 +/- 5	170 +/- 5	170 +/- 5
Inlet Fuel [°F]	100 +/- 5	100 +/- 5	100 +/- 5
Oil Sump [°F]	245 +/- 5	230 +/- 5	NS (190)

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was Jet-A with the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 20 hrs for used oil analysis. Engine oil analysis consisted of the following tests outlined in Table 3. All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Table 3 - Used Oil Analysis Procedures

Daily Used Oil Analysis	
ASTM D445	Kinematic Viscosity @ 100°C
ASTM D5185	Wear Metals by ICP
ASTM D4739	Total Base Number
ASTM D664	Total Acid Number

Used oil analysis results can be seen in the engine oil analysis section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred daily after the completion of the 4hr soak prior to restarting testing. All oil additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

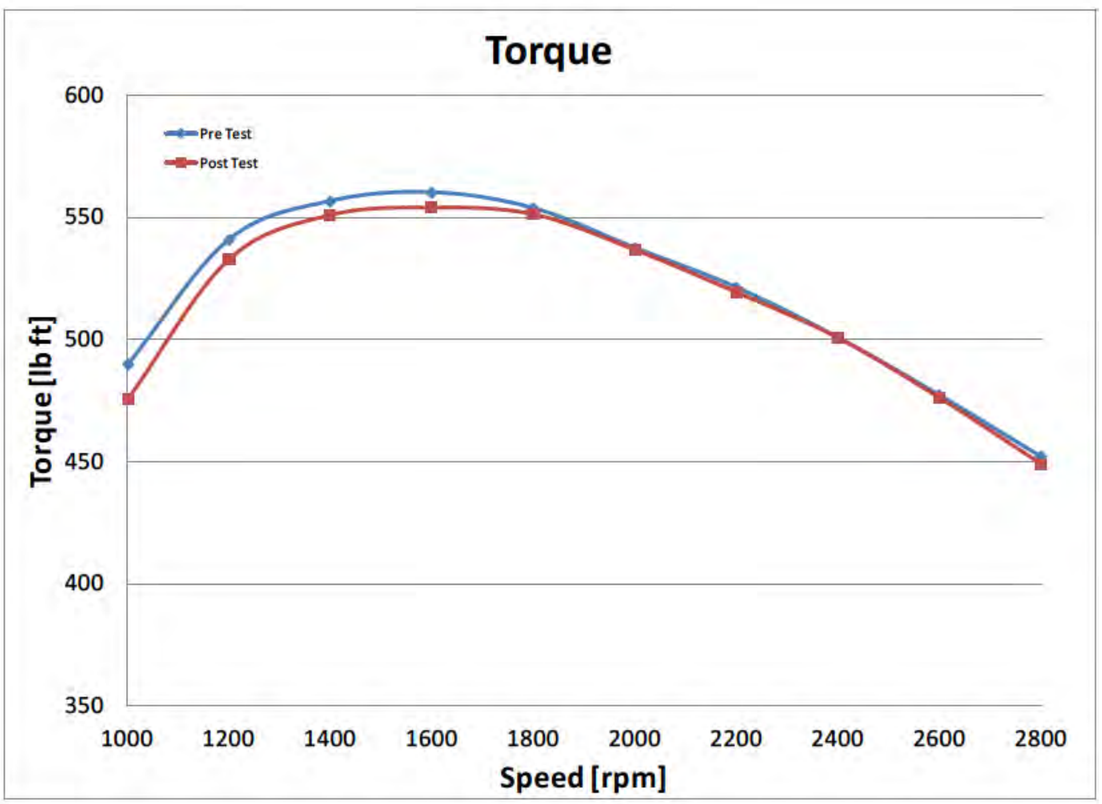
Engine Operating Conditions Summary

Below is a summary of the engine operating conditions over the test duration. The complete 240hr test schedule was completed by the lubricant.

		Peak Power (2800 RPM)		Peak Torque (1600 RPM)		Idle Conditions (950 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	2799.86	5.69	1600.06	4.94	870.25	4.75
Torque*	ft*lb	462.47	42.57	565.71	36.31	--	--
Fuel Flow	lb/hr	92.03	1.26	63.85	0.92	2.61	0.44
Power*	bhp	246.50	22.22	172.32	10.55	--	--
BSFC*	lb/bhp*hr	0.376	0.034	0.372	0.023	--	--
Engine Blowby	acfm	8.93	1.77	6.62	0.78	3.78	0.70
Relative Humidity	%	42.78	17.10	44.25	17.58	44.75	17.57
Temperatures:							
Coolant In	°F	160.61	1.46	158.70	1.59	163.64	9.19
Coolant Out	°F	170.00	1.30	169.99	1.39	166.22	9.40
Oil Galley	°F	218.88	2.35	210.04	1.04	189.01	15.46
Oil Sump	°F	245.00	0.46	230.00	0.41	192.28	15.96
Fuel In	°F	100.00	0.81	100.05	0.82	99.88	2.50
Dry Bulb	°F	81.24	6.86	80.18	7.74	78.82	7.32
Intake Air	°F	76.89	3.87	75.73	3.12	75.51	2.40
Air After Turbo	°F	281.87	4.15	202.44	3.01	83.06	3.08
Air After Supercharger	°F	270.02	3.98	198.63	2.90	142.50	12.39
Cylinder 1 Exhaust	°F	785.51	8.26	617.25	6.39	202.98	9.61
Cylinder 2 Exhaust	°F	846.25	9.05	722.13	6.27	214.73	10.06
Cylinder 3 Exhaust	°F	803.45	9.09	692.67	6.50	189.46	9.15
Cylinder 4 Exhaust	°F	804.89	9.06	660.59	11.71	190.13	12.14
Cylinder 5 Exhaust	°F	889.94	10.22	847.96	12.15	200.92	11.06
Cylinder 6 Exhaust	°F	834.71	7.65	798.13	9.95	181.75	10.54
Exhaust Exit Left	°F	876.29	8.52	854.90	8.43	194.56	10.30
Exhaust Exit Right	°F	867.27	9.68	802.86	9.25	209.61	9.45
Exhaust After Turbo	°F	760.36	262.35	803.02	318.79	389.43	476.98
Pressures:							
Oil Galley	psiG	41.09	1.09	26.24	0.80	14.95	2.43
Ambient Pressure	psiA	14.36	0.06	14.35	0.06	14.36	0.06
Pressure After Turbo	psiG	20.08	0.44	11.27	0.26	0.21	0.32
Pressure After Supercharger	psiG	22.26	0.47	10.86	0.27	0.55	0.14
Pressure Exhaust Left	psiG	19.25	0.38	9.97	0.21	0.40	0.11
Pressure Exhaust Right	psiG	18.31	0.34	9.43	0.17	0.44	0.09
Pressure Exhaust After Turbo	psiG	0.66	0.16	0.06	0.04	-0.01	0.07
Fuel Pressure	psiG	30.55	2.33	12.01	1.75	4.67	0.40

* Non-corrected Values

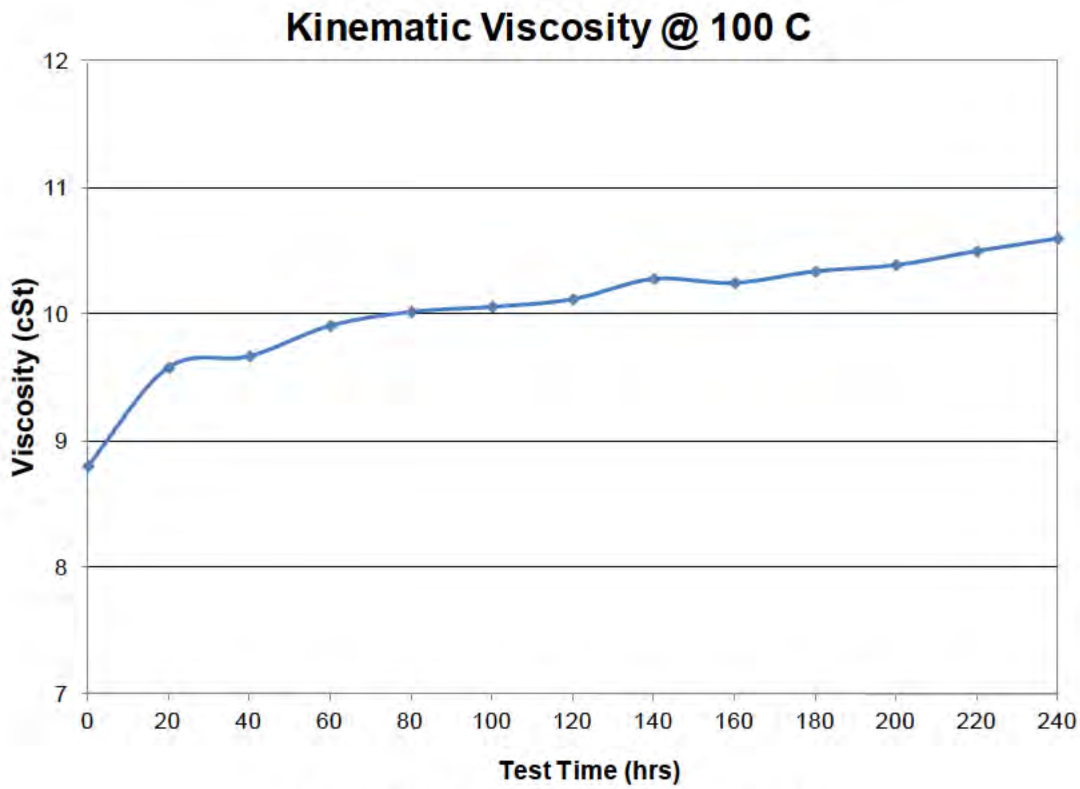
Engine Performance Curves

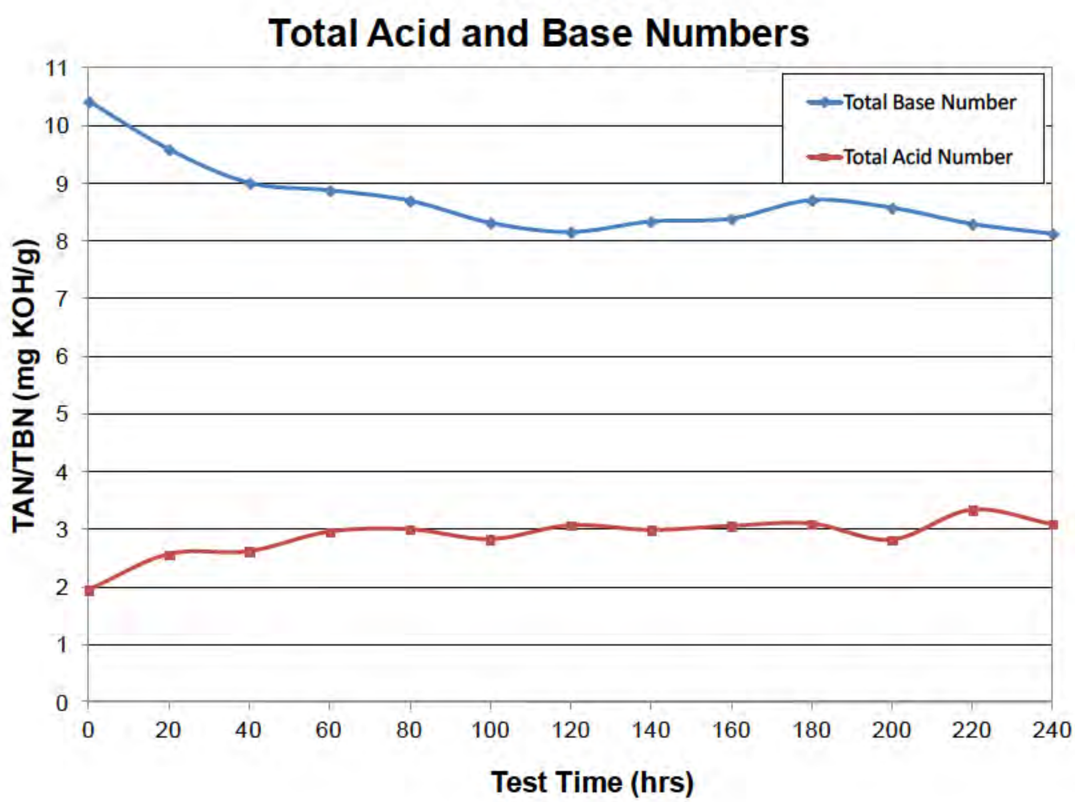


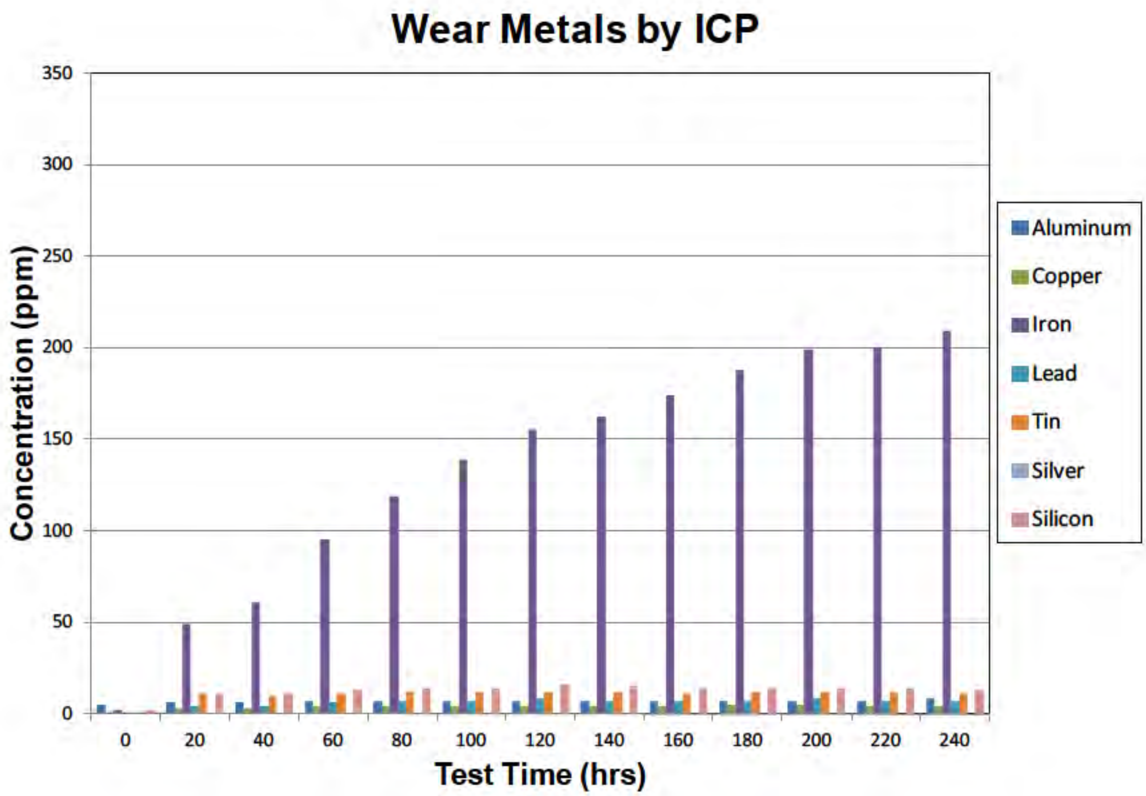
Engine Oil Analysis

Property	ASTM Test	Test Hours												
		0	20	40	60	80	100	120	140	160	180	200	220	240
Viscosity @ 100°C (cSt)	D445	8.8	9.6	9.7	9.9	10.0	10.1	10.1	10.3	10.3	10.3	10.4	10.5	10.6
Total Base Number (mg KOH/g)	D4739	10.4	9.6	9.0	8.9	8.7	8.3	8.2	8.3	8.4	8.7	8.6	8.3	8.1
Total Acid Number (mg KOH/g)	D664	1.9	2.6	2.6	3.0	3.0	2.8	3.1	3.0	3.1	3.1	2.8	3.3	3.1
Wear Metals (ppm)	D5185													
Al		5	6	6	7	7	7	7	7	7	7	7	7	8
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		<1	<1	2	<1	<1	<1	1	2	2	<1	2	<1	<1
Ca		3563	3744	3710	3700	3762	3911	3912	3843	4152	3993	3987	3968	4134
Cr		<1	2	2	3	4	4	4	4	4	4	5	4	5
Cu		<1	3	3	4	4	4	4	4	4	5	5	4	4
Fe		2	49	61	95	119	139	155	162	174	188	199	200	209
Pb		<1	4	4	6	7	7	8	7	7	7	8	7	7
Mg		11	19	15	15	13	16	14	15	13	15	14	13	14
Mn		<1	<1	<1	1	2	2	2	2	2	2	2	2	2
Mo		<1	5	6	7	8	9	10	11	11	12	12	12	13
Ni		<1	<1	<1	1	1	1	1	2	2	2	2	2	2
P		1314	1271	1251	1249	1172	1244	1209	1199	1187	1226	1216	1182	1261
Si		2	11	11	13	14	14	16	15	14	14	14	14	13
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		6	9	8	9	8	10	10	8	9	8	9	8	9
Sn		<1	11	10	11	12	12	12	12	11	12	12	12	11
Zn		1863	1873	1870	1913	1902	1930	1887	1907	1929	1935	1927	1952	1906
K		8	8	11	9	11	9	9	8	10	9	9	9	10
Sr		1	1	2	1	2	2	<1	2	2	1	2	2	<1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Engine Oil Analysis Trends






Wear Metals by ICP
Concentration (ppm)
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
220
240
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

Oil Consumption Data

Average oil consumption per test hour was 0.359 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
20 hr	8.8	0.2	8.6	8.6
40 hr	7.44	0.22	7.22	15.82
60 hr	8.76	0.22	8.54	24.36
80 hr	8.32	0.23	8.09	32.45
100 hr	6.96	0.23	6.73	39.18
120 hr	7.98	0.22	7.76	46.94
140 hr	6.81	0.22	6.59	53.53
160 hr	6.02	0.23	5.79	59.32
180 hr	7.34	0.23	7.11	66.43
200 hr	7.32	0.23	7.09	73.52
220 hr	7.29	0.22	7.07	80.59
240 hr	8.4	0.23	8.17	88.76
	Initial Fill	33.6	**Total Additions**	91.44
	EOT Drain	36.17	**Total Samples**	2.68

(Initial Fill + Additions)	125.04
(EOT Drain + Samples)	38.85
Total Oil Consumption	86.19

Engine Measurements

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA	Out of Round
1L	13mm From Top	3.8761	3.8762		0.0001
	25mm Above Port	3.8764	3.8762	3.8762	0.0002
	25mm Below Port	3.8763	3.8757		0.0006
	13mm From Bottom	3.8766	3.8763		0.0003
	Taper	0.0005	0.0006		
2L	13mm From Top	3.8763	3.8763		0.0000
	25mm Above Port	3.8762	3.8762	3.8762	0.0000
	25mm Below Port	3.8760	3.8760		0.0000
	13mm From Bottom	3.8766	3.8763		0.0003
	Taper	0.0006	0.0003		
3L	13mm From Top	3.8762	3.8761		0.0001
	25mm Above Port	3.8760	3.8760	3.8760	0.0000
	25mm Below Port	3.8759	3.8757		0.0002
	13mm From Bottom	3.8760	3.8762		0.0002
	Taper	0.0003	0.0005		
1R	13mm From Top	3.8763	3.8763		0.0000
	25mm Above Port	3.8761	3.8761	3.8763	0.0000
	25mm Below Port	3.8760	3.8760		0.0000
	13mm From Bottom	3.8765	3.8767		0.0002
	Taper	0.0005	0.0007		
2R	13mm From Top	3.8766	3.8761		0.0005
	25mm Above Port	3.8765	3.8761	3.8763	0.0004
	25mm Below Port	3.8762	3.8759		0.0003
	13mm From Bottom	3.8766	3.8765		0.0001
	Taper	0.0004	0.0006		
3R	13mm From Top	3.8766	3.8762		0.0004
	25mm Above Port	3.8764	3.8762	3.8763	0.0002
	25mm Below Port	3.8762	3.8760		0.0002
	13mm From Bottom	3.8764	3.8765		0.0001
	Taper	0.0004	0.0005		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA	Out of Round
1L	13mm From Top	3.8776	3.8763		0.0013
	25mm Above Port	3.8768	3.8763	3.8766	0.0005
	25mm Below Port	3.8765	3.8760		0.0005
	13mm From Bottom	3.8766	3.8766		0.0000
	Taper	0.0011	0.0006		
2L	13mm From Top	3.8770	3.8765		0.0005
	25mm Above Port	3.8765	3.8763	3.8765	0.0002
	25mm Below Port	3.8763	3.8763		0.0000
	13mm From Bottom	3.8766	3.8766		0.0000
	Taper	0.0007	0.0003		
3L	13mm From Top	N/A	N/A		N/A
	25mm Above Port	N/A	N/A	N/A	N/A
	25mm Below Port	N/A	N/A		N/A
	13mm From Bottom	N/A	N/A		N/A
	Taper	0.0000	0.0000		
1R	13mm From Top	3.8770	3.8764		0.0006
	25mm Above Port	3.8765	3.8764	3.8766	0.0001
	25mm Below Port	3.8763	3.8763		0.0000
	13mm From Bottom	3.8765	3.8770		0.0005
	Taper	0.0007	0.0007		
2R	13mm From Top	3.8770	3.8763		0.0007
	25mm Above Port	3.8767	3.8761	3.8765	0.0006
	25mm Below Port	3.8767	3.8761		0.0006
	13mm From Bottom	3.8765	3.8768		0.0003
	Taper	0.0005	0.0007		
3R	13mm From Top	3.8771	3.8763		0.0008
	25mm Above Port	3.8766	3.8763	3.8765	0.0003
	25mm Below Port	3.8765	3.8761		0.0004
	13mm From Bottom	3.8763	3.8765		0.0002
	Taper	0.0008	0.0004		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA Change	Out of Round
1L	13mm From Top	0.0015	0.0001		0.0012
	25mm Above Port	0.0004	0.0001	0.0004	0.0003
	25mm Below Port	0.0002	0.0003		0.0001
	13mm From Bottom	0.0000	0.0003		0.0003
	Taper	0.0015	0.0002		
2L	13mm From Top	0.0007	0.0002		0.0005
	25mm Above Port	0.0003	0.0001	0.0003	0.0002
	25mm Below Port	0.0003	0.0003		0.0000
	13mm From Bottom	0.0000	0.0003		0.0003
	Taper	0.0007	0.0002		
3L	13mm From Top	N/A	N/A		N/A
	25mm Above Port	N/A	N/A	N/A	N/A
	25mm Below Port	N/A	N/A		N/A
	13mm From Bottom	N/A	N/A		N/A
	Taper	N/A	N/A		
1R	13mm From Top	0.0007	0.0001		0.0006
	25mm Above Port	0.0004	0.0003	0.0003	0.0001
	25mm Below Port	0.0003	0.0003		0.0000
	13mm From Bottom	0.0000	0.0003		0.0003
	Taper	0.0007	0.0002		
2R	13mm From Top	0.0004	0.0002		0.0002
	25mm Above Port	0.0002	0.0000	0.0002	0.0002
	25mm Below Port	0.0005	0.0002		0.0003
	13mm From Bottom	0.0001	0.0003		0.0002
	Taper	0.0004	0.0003		
3R	13mm From Top	0.0005	0.0001		0.0004
	25mm Above Port	0.0002	0.0001	0.0002	0.0001
	25mm Below Port	0.0003	0.0001		0.0002
	13mm From Bottom	0.0001	0.0000		0.0001
	Taper	0.0004	0.0001		
Avgerage All Cylinders	13mm From Top	0.0008	0.0001		
	25mm Above Port	0.0003	0.0001		
	25mm Below Port	0.0003	0.0002		
	13mm From Bottom	0.0000	0.0002		

Pre-Test Liner Surface Finish, µm

Pre Test Liner Surface Finish, µm					
1L	2L	3L	1R	2R	3R
1.46	1.33	1.46	1.49	1.31	1.32

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	3.8762	3.8707	0.0056
	2	3.8762	3.8717	0.0046
	3	3.8760	3.8712	0.0048
	4	3.8763	3.8696	0.0067
	5	3.8763	3.8705	0.0058
	6	3.8763	3.8700	0.0063
Post - Test	1	3.8766	3.8698	0.0068
	2	3.8765	3.8700	0.0065
	3	N/A	3.8699	N/A
	4	3.8766	3.8688	0.0078
	5	3.8765	3.8693	0.0072
	6	3.8765	3.8696	0.0069

Connecting Rod Bearing Mass Change, grams

Rod Bearing	Shell	Before	After	Change
1L	Top	73.5096	73.4845	0.0251
	Bottom	68.4050	68.3979	0.0071
2L	Top	73.5891	73.5602	0.0289
	Bottom	67.9048	67.9006	0.0042
3L	Top	73.5592	73.5377	0.0215
	Bottom	68.0659	68.0599	0.0060
1R	Top	73.7570	73.7359	0.0211
	Bottom	67.8936	67.8878	0.0058
2R	Top	73.5076	73.4869	0.0207
	Bottom	67.9593	67.9563	0.0030
3R	Top	73.4451	73.4258	0.0193
	Bottom	67.8821	67.8766	0.0055

Maximum	0.0289
Average	0.0140

Slipper Bushing Mass Change, grams

Slipper Bushing	Before	After	Change
1L	56.1310	55.9758	0.1552
2L	56.0567	55.9313	0.1254
3L	56.0873	55.9811	0.1062
1R	56.0515	55.8908	0.1607
2R	56.0870	55.9288	0.1582
3R	55.7503	55.5740	0.1763

Maximum	0.1763
Average	0.1470

Pre-Test Slipper Bushing Tin Plate Thickness, inches

Slipper Bushing Tin Plate Thickness					
1L	2L	3L	1R	2R	3R
0.02355	0.02350	0.02350	0.02245	0.02300	0.02340

Top, Second, and Third Ring Radial Measurements, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1L	1	0.15650	0.15520	0.00130
	2	0.15585	0.15510	0.00075
	3	0.15635	0.15555	0.00080
	4	0.15575	0.15485	0.00090
	5	0.15685	0.15535	0.00150
2L	1	0.15650	0.15565	0.00085
	2	0.15800	0.15760	0.00040
	3	0.15695	0.15665	0.00030
	4	0.15635	0.15600	0.00035
	5	0.15720	0.15635	0.00085
3L	1	0.15755	0.15620	0.00135
	2	0.15620	0.15560	0.00060
	3	0.15630	0.15595	0.00035
	4	0.15645	0.15600	0.00045
	5	0.15750	0.15610	0.00140
1R	1	0.15650	0.15525	0.00125
	2	0.15625	0.15575	0.00050
	3	0.15760	0.15710	0.00050
	4	0.15750	0.15705	0.00045
	5	0.15685	0.15550	0.00135
2R	1	0.15465	0.15365	0.00100
	2	0.15500	0.15455	0.00045
	3	0.15645	0.15610	0.00035
	4	0.15690	0.15650	0.00040
	5	0.15620	0.15555	0.00065
3R	1	0.15545	0.15395	0.00150
	2	0.15460	0.15375	0.00085
	3	0.15595	0.15530	0.00065
	4	0.15675	0.15590	0.00085
	5	0.15610	0.15570	0.00040
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.00150
Average	0.00078

Second Ring				
Cylinder	Position	Before	After	Delta
1L	1	0.14690	0.14570	0.00120
	2	0.14775	0.14660	0.00115
	3	0.14735	0.14615	0.00120
	4	0.14680	0.14580	0.00100
	5	0.14730	0.14625	0.00105
2L	1	0.14660	0.14590	0.00070
	2	0.14840	0.14765	0.00075
	3	0.14725	0.14640	0.00085
	4	0.14695	0.14625	0.00070
	5	0.14685	0.14605	0.00080
3L	1	0.14725	0.14615	0.00110
	2	0.14785	0.14665	0.00120
	3	0.17860	0.14760	0.03100
	4	0.14850	0.14760	0.00090
	5	0.14735	0.14625	0.00110
1R	1	0.14670	0.14530	0.00140
	2	0.14745	0.14655	0.00090
	3	0.14750	0.14640	0.00110
	4	0.14645	0.14540	0.00105
	5	0.14625	0.14470	0.00155
2R	1	0.14670	0.14610	0.00060
	2	0.14810	0.14745	0.00065
	3	0.14755	0.14675	0.00080
	4	0.14745	0.14690	0.00055
	5	0.14710	0.14640	0.00070
3R	1	0.14795	0.14695	0.00100
	2	0.14720	0.14645	0.00075
	3	0.14635	0.14525	0.00110
	4	0.14700	0.14600	0.00100
	5	0.14775	0.14655	0.00120
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.03100
Average	0.00197

Third Ring				
Cylinder	Position	Before	After	Delta
1L	1	0.14665	0.14590	0.00075
	2	0.14705	0.14635	0.00070
	3	0.14755	0.14675	0.00080
	4	0.14680	0.14630	0.00050
	5	0.14660	0.14590	0.00070
2L	1	0.14665	0.14620	0.00045
	2	0.14760	0.14710	0.00050
	3	0.14765	0.14730	0.00035
	4	0.14705	0.14680	0.00025
	5	0.14690	0.14650	0.00040
3L	1	0.14800	0.14745	0.00055
	2	0.14735	0.14700	0.00035
	3	0.14785	0.14745	0.00040
	4	0.14845	0.14805	0.00040
	5	0.14830	0.14775	0.00055
1R	1	0.14795	0.14710	0.00085
	2	0.14730	0.14700	0.00030
	3	0.14610	0.14560	0.00050
	4	0.14670	0.14610	0.00060
	5	0.14725	0.14585	0.00140
2R	1	0.14720	0.14680	0.00040
	2	0.14730	0.14705	0.00025
	3	0.14740	0.14715	0.00025
	4	0.14815	0.14790	0.00025
	5	0.14745	0.14710	0.00035
3R	1	0.14650	0.14585	0.00065
	2	0.14770	0.14720	0.00050
	3	0.14775	0.14710	0.00065
	4	0.14635	0.14545	0.00090
	5	0.14645	0.14550	0.00095
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.00140
Average	0.00055

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Increase
1L	1	0.041	0.045	0.004
	2	0.028	0.039	0.011
	3	0.030	0.037	0.007
	4	0.019	0.025	0.006
	5a	0.016	0.022	0.006
	5b	0.017	0.024	0.007
2L	1	0.030	0.035	0.005
	2	0.031	0.038	0.007
	3	0.031	0.036	0.005
	4	0.019	0.025	0.006
	5a	0.017	0.022	0.005
	5b	0.017	0.022	0.005
3L	1	0.032	0.035	0.003
	2	0.029	0.039	0.010
	3	0.030	0.035	0.005
	4	0.018	0.023	0.005
	5a	0.017	0.023	0.006
	5b	0.017	0.023	0.006
1R	1	0.031	0.036	0.005
	2	0.030	0.040	0.010
	3	0.030	0.037	0.007
	4	0.017	0.022	0.005
	5a	0.017	0.024	0.007
	5b	0.018	0.025	0.007
2R	1	0.031	0.037	0.006
	2	0.029	0.036	0.007
	3	0.029	0.034	0.005
	4	0.016	0.021	0.005
	5a	0.018	0.024	0.006
	5b	0.017	0.023	0.006
3R	1	0.031	0.036	0.005
	2	0.031	0.040	0.009
	3	0.031	0.038	0.007
	4	0.018	0.024	0.006
	5a	0.019	0.025	0.006
	5b	0.018	0.024	0.006

Ring No. 1 max increase	0.006
Ring No. 2 max increase	0.011
Ring No. 3 max increase	0.007
Ring No. 4 max increase	0.006
Ring No. 5a max increase	0.007
Ring No. 5b max increase	0.007

Ring No. 1 avg increase	0.005
Ring No. 2 avg increase	0.009
Ring No. 3 avg increase	0.006
Ring No. 4 avg increase	0.006
Ring No. 5a avg increase	0.006
Ring No. 5b avg increase	0.006

Piston Ring Mass Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1L	1	22.8443	22.8093	0.0350
	2	20.1878	20.0504	0.1374
	3	20.1517	20.0781	0.0736
	4	27.4218	27.4054	0.0164
	5	24.3984	24.3678	0.0306
2L	1	23.1662	23.1421	0.0241
	2	20.2026	20.1275	0.0751
	3	20.1997	20.1747	0.0250
	4	27.4120	27.3898	0.0222
	5	24.3628	24.3300	0.0328
3L	1	23.0348	23.0003	0.0345
	2	20.3096	20.1994	0.1102
	3	20.2840	20.2455	0.0385
	4	27.4054	27.3867	0.0187
	5	24.3822	24.3542	0.0280
1R	1	23.2131	23.1834	0.0297
	2	20.1729	20.0421	0.1308
	3	20.1572	20.0988	0.0584
	4	27.4500	27.4267	0.0233
	5	24.3835	24.3523	0.0312
2R	1	22.9615	22.9389	0.0226
	2	20.1967	20.1415	0.0552
	3	20.2070	20.1898	0.0172
	4	27.5839	27.5625	0.0214
	5	24.4885	24.4558	0.0327
3R	1	22.9341	22.9020	0.0321
	2	20.1809	20.0737	0.1072
	3	20.1792	20.1151	0.0641
	4	27.3799	27.3598	0.0201
	5	27.2522	27.2059	0.0463

Ring No. 1 max decrease	0.0350
Ring No. 2 max decrease	0.1374
Ring No. 3 max decrease	0.0736
Ring No. 4 max decrease	0.0233
Ring No. 5 max decrease	0.0463

Ring No. 1 avg decrease	0.0297
Ring No. 2 avg decrease	0.1026
Ring No. 3 avg decrease	0.0461
Ring No. 4 avg decrease	0.0203
Ring No. 5 avg decrease	0.0336

Oil Control & Expander Ring Tension, pounds

	Oil Control & Expander Ring Tension					
	1L	2L	3L	1R	2R	3R
Top Oil Ring	7.1	7.4	7.2	7.8	8.5	7.5
Second Oil Ring	7.6	8.0	8.1	8.4	8.1	8.0

NOTE – To be used as reference only.
Measurements taken with non-calibrated legacy equipment.

Post Test Engine Ratings

Piston Ratings, Demerits

Ratings	**Cylinder Number**						
	1L	2L	3L	1R	2R	3R	**Avg**
Ring Sticking (F=Free, CS=Cold Stuck, HS=Hot Stuck, CP=Collapsed Ring, No. Denotes % Of Ring Circumference)							
Top	F	F	F	F	F	F	--
Second	F	CS 5%	CS 10%	F	F	F	--
Third	F	F	F	F	F	F	--
Oil Control Rings	F	F	F	F	F	F	--
2nd Ring Carbon							
Heavy Carbon	62	10	78	5	4	40	--
Light Carbon	38	90	22	46	86	60	--
Piston Carbon, Demerits							
No.1 Groove	48.00	57.50	73.50	72.50	66.75	57.25	62.58
No.2 Groove	42.25	26.50	37.75	37.75	36.25	30.25	35.13
No.3 Groove	25.00	23.00	25.00	25.00	16.50	25.00	23.25
No.1 Land	40.75	42.25	54.25	28.75	43.00	34.00	40.50
No.2 Land	59.50	61.00	65.50	63.25	59.50	50.50	59.88
No.3 Land	15.75	17.00	17.00	20.50	20.50	10.00	16.79
No.4 Land	10.00	3.00	7.50	6.75	2.50	8.75	6.42
Piston Lacquer, Demerits							
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.3 Groove	0.00	0.22	0.00	0.00	1.64	0.00	0.31
No.1 Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.3 Land	1.64	1.25	1.12	1.38	1.21	2.52	1.52
No.4 Land	1.97	3.12	2.00	2.33	3.32	2.69	2.57
Total, Demerits	244.86	234.84	283.62	258.21	251.17	220.96	248.94
Miscellanous							
Top Groove Fill, %	47	55	76	77	60	57	62.00
Intermediate Groove Fill, %	55	60	70	59	57	52	58.83
Top Land Heavy Carbon, %	21	23	39	5	24	12	20.67
Top Lan Flaked Carbon, %	1	0	0	0	0	0	0.17

Ring Face Distress, Demerits

Cylinder No.	Ring No.	Extreme Distress (1.00) % Area	Heavy Distress (0.75) % Area	Medium Distress (0.50) % Area	Light Distress (0.25) % Area	No Distress (0.00) % Area	Total Demerits
1L	1				7	93	0.0175
	2						0
	3						0
2L	1				8	92	0.02
	2						0
	3						0
3L	1				5	95	0.0125
	2						0
	3						0
1R	1				10	90	0.025
	2						0
	3						0
2R	1				9	91	0.0225
	2						0
	3						0
3R	1				22	78	0.055
	2						0
	3						0

Piston Ring Face Distress	Fire Ring	2nd Ring	3rd Ring
Average Demerits	0.0254	0.0000	0.0000

EOT Cylinder Liner Ratings, % Area

	Cylinder Liner Ratings					
	% Scuffing		Total % Area Scuffed	% Polish		Total % Area Polished
	T	AT		T	AT	
1L	0	0	0	15	4	19
2L	0	0	0	10	12	22
3L	0	0	0	5	2	7
1R	0	0	0	5	2	7
2R	0	0	0	2	7	9
3R	0	0	0	4	2	6
Percent of total ring travel area						

Periodic Bore Inspection Results, % Area

Periodic Bore Inspection, % Scuffed Area				
Cyl	**0hr**	**60hr**	**120hr**	**180hr**
1L	0	0	0	0
2L	0	0	0	0
3L	0	0	3	3
1R	0	0	0	0
2R	0	0	0	0
3R	0	0	0	0

Piston Skirt Ratings

	Piston Skirt Ratings	
	Thrust	Anti-Thrust
1L	Few Light Scratches & 1% Scuffing	Few Light Scratches
2L	Few Light Scratches	Few Light Scratches
3L	Few Light Scratches	Few Very Light Scratches
1R	Few Light Scratches	Few Light Scratches & 1% Scuffing
2R	Few Light Scratches	Few Light Scratches & 1% Scuffing
3R	Few Very Light Scratches	Few Light Scraches & 1% Scuffing

EOT Intake Port Plugging & Slipper Bushing Exposed Copper, %

Intake Port Plugging	
1L	2
2L	2
3L	3
1R	3
2R	2
3R	3
Average	2.5

Slipper Bushing % Exposed Copper	
1L	1
2L	1
3L	2
1R	2
2R	1
3R	2
Average	1.50

PHOTOGRAPHS

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

Ring Pack 1 Left

Ring Pack 1 Right

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

Piston 1 Left Thrust

Piston 1 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

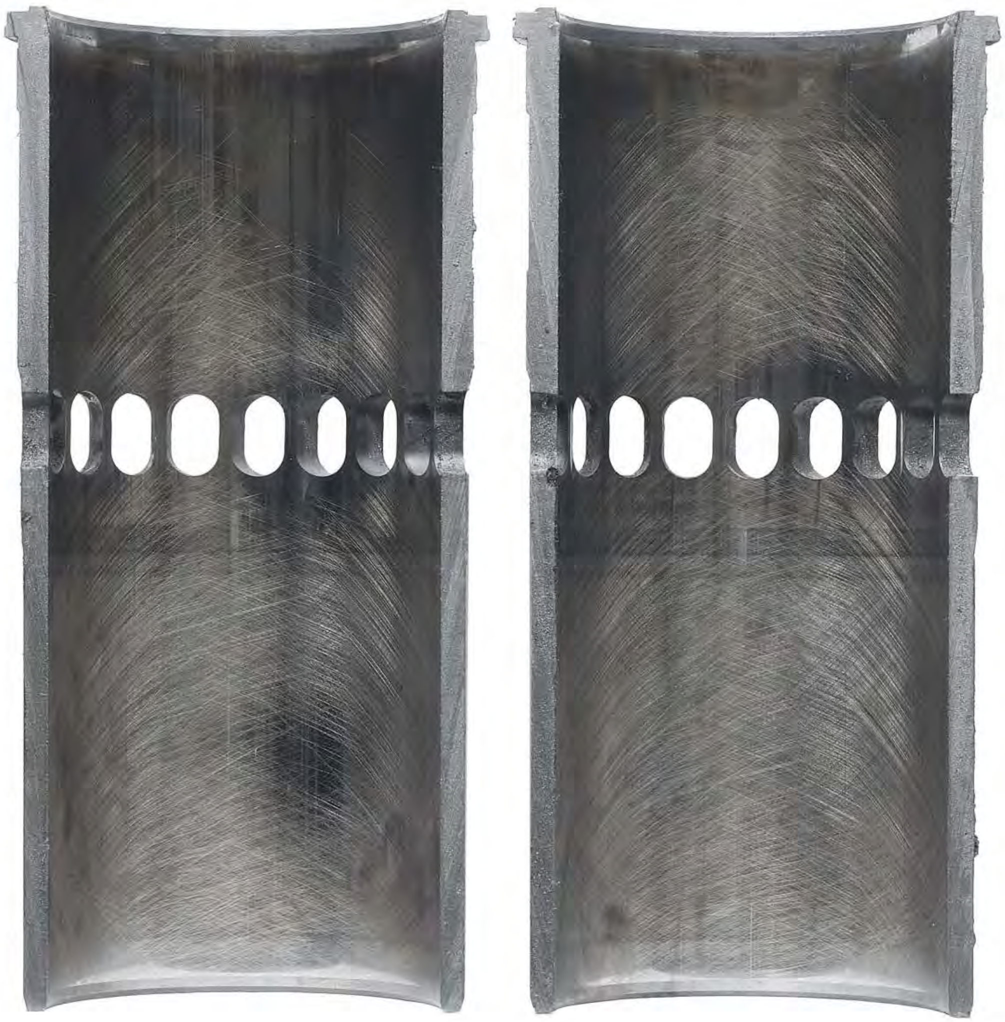
Piston 1 Right Thrust

Piston 1 Right Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

Liner 1 Left Thrust and Anti-thrust



DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	EOT Date:	10/27/11
Test No.:	LO268869-6V53T1-T-240	Test Length:	240

Liner 1 Right Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

Ring Pack 2 Left

Ring Pack 2 Right

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	EOT Date:	10/27/11
Test No.:	LO268869-6V53T1-T-240	Test Length:	240

Piston 2 Left Thrust

Piston 2 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

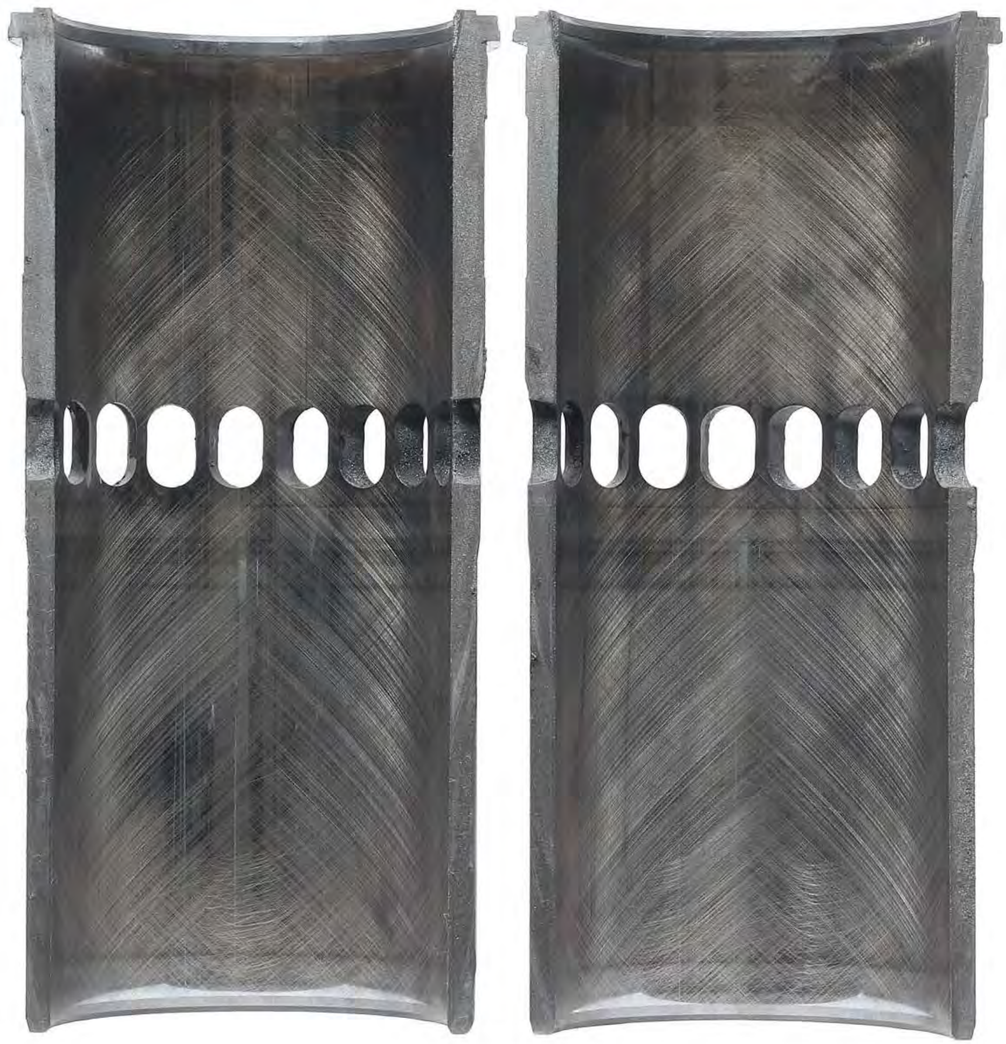
Piston 2 Right Thrust

Piston 2 Right Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	EOT Date:	10/27/11
Test No.:	LO268869-6V53T1-T-240	Test Length:	240

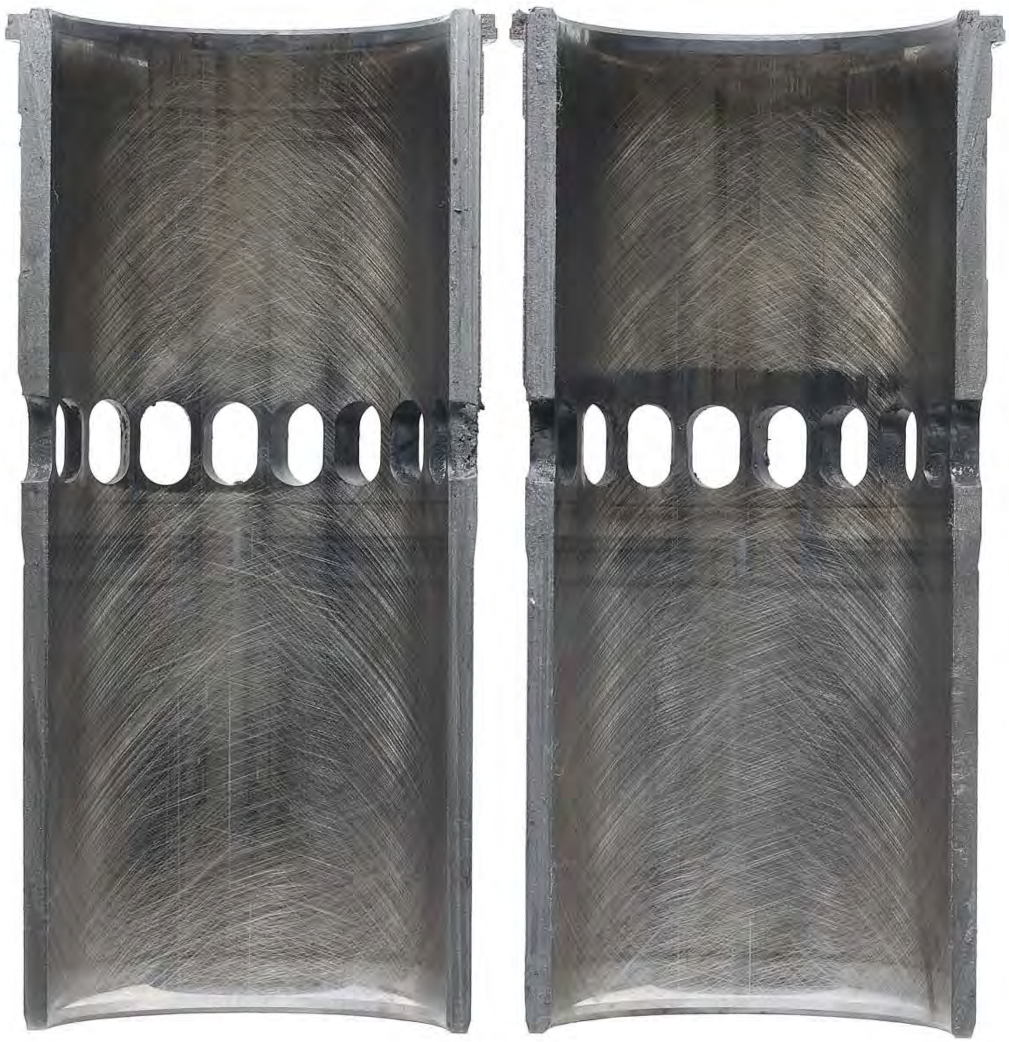
Liner 2 Left Thrust and Anti-thrust



DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	EOT Date:	10/27/11
Test No.:	LO268869-6V53T1-T-240	Test Length:	240

Liner 2 Right Thrust and Anti-thrust



DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

Ring Pack 3 Left

Ring Pack 3 Right

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	EOT Date:	10/27/11
Test No.:	LO268869-6V53T1-T-240	Test Length:	240

Piston 3 Left Thrust

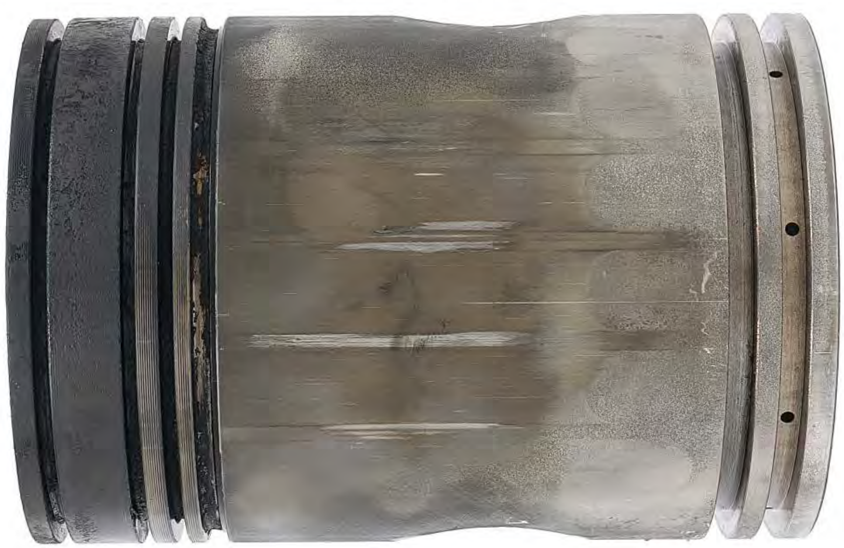
Piston 3 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

Piston 3 Right Thrust

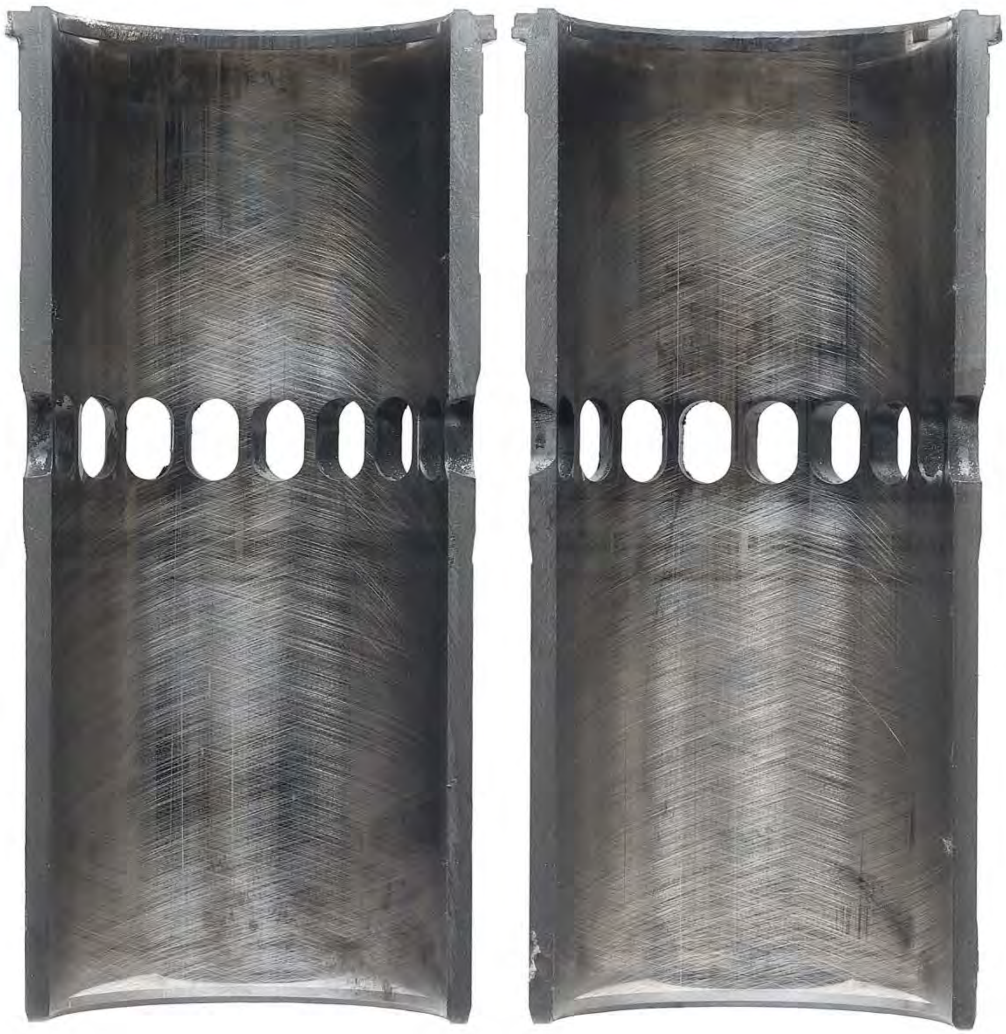
Piston 3 Right Anti-thrust



DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	EOT Date:	10/27/11
Test No.:	LO268869-6V53T1-T-240	Test Length:	240

Liner 3 Left Thrust and Anti-thrust



DDC 6V53T - Tracked Vehicle Cycle

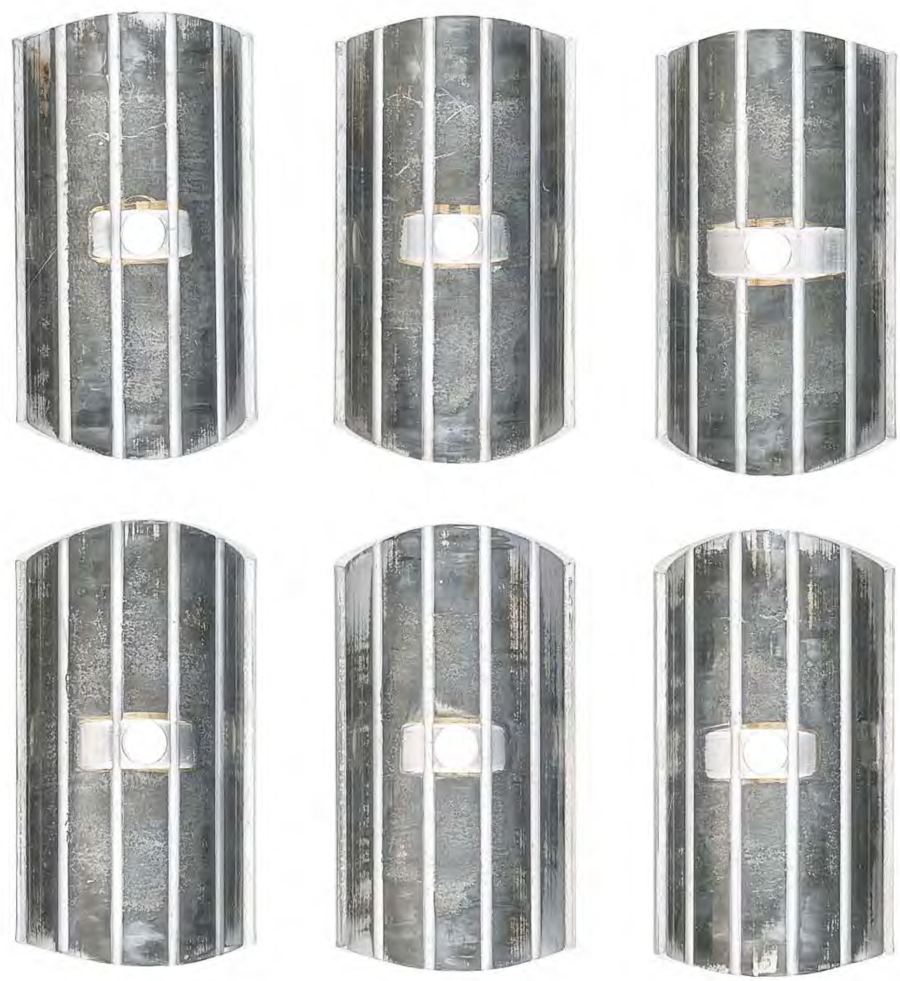
Oil Code:	LO268869	EOT Date:	10/27/11
Test No.:	LO268869-6V53T1-T-240	Test Length:	240

Liner 3 Right Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

Slipper Bushings 1R, 2R, 3R



Slipper Bushings 1L, 2L, 3L

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO268869	**EOT Date:**	10/27/11
Test No.:	LO268869-6V53T1-T-240	**Test Length:**	240

Connecting Rod Bearings

Upper 1L, 2L, 3L, 1R, 2R, 3R **Lower 1L, 2L, 3L, 1R, 2R, 3R**

APPENDIX – C1
ROLLER FOLLOWER WEAR TEST
LO-268869

D 5966
Roller Follower Wear Test

Version 20040401

Title / Validity Declaration Page

Conducted for

U.S. ARMY TARDEC

V	V =	Valid; The Reference Oil / Non-Reference Oil was Evaluated in Accordance with the Test Prodecure.
	I =	Invalid; The Reference Oil / Non-Reference Oil was Evaluated in Accordance with the Test Procedure.

Stand: 65	**Stand Run No.:** 404	**Engine No.:** 222	**Engine Run No.:** 9
End of Test Date: 20120203		**End of Test Time:** 16:59 CST	
Oil Code:* LO-268869			
Formulation / Stand Code:[A]			
Alternate Codes:[B]			

In my opinion this test has been conducted in a valid manner in accordance with the Test Method D 5966 and the appropriate amendments through the information letter system. The remarks included in the report describe the anomalies associated with this test.

The results of this report relate only to the items tested.

This report shall not be reproduced, except in full, without the written approval of Southwest Research Institute®.

* *CMIR or Non-Reference Oil Code*

[A] *ACC -Registered Tests Only*

[B] *When Provided or Required by Client*

Submitted by:

Southwest Research Institute (R)
Testing Laboratory

Signature

Perry Grosch
Typed Name

Principal Research Technologist
Title

D 5966
Roller Follower Wear Test
Test Identification Cover Sheet
Test Lab Affidavit
Form 1

Reference Oil Test

Lab	Stand	Stand Run No.	Engine	Engine Run No.
SR	65		222	

Start Date	Date Completed	EOT of Test Time	Test Length
			0

CMIR	TMC Oil Code	Viscosity Grade

Laboratory Oil Code	
Engine Displacement	6.5L

Average Wear (mils)

Non-Reference Oil Test

Lab	Stand	Stand Run No.	Engine	Engine Run No.
SR	65	404	222	9

Start Date	Date Completed	EOT of Test Time	Test Length
20120201	20120203	16:59	50

Oil Code	Viscosity Grade
LO-268869	N/A

Laboratory Oil Code	268869

Formulation / Stand Code

Average Wear (mils)	Severity Adjustment	Adjustment Average Wear
0.28	0.00	0.28

D 5966
Roller Follower Wear Test
Summary of Roller Follower Wear
Form 2

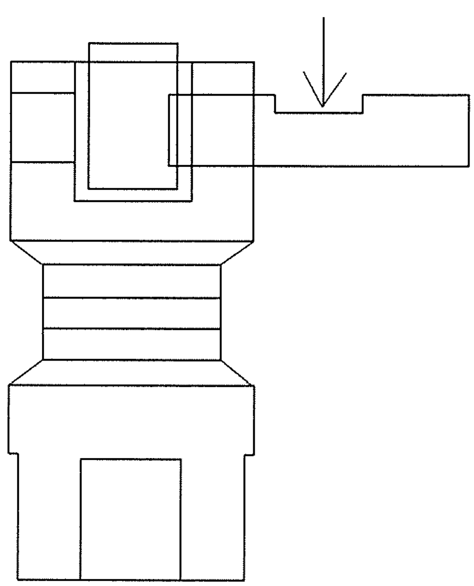
Laboratory: SR	**EOT Date:** 20120203
Test Number: * 65-404-222-9	
Oil Code: LO-268869	
Formulation / Stand Code:	

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Lifter Part Number
171098650

Profilometer Wear Measurements (mils)			
Lifter Number	**Wear (mils)**	**Lifter Number**	**Wear (mils)**
1L	0.21	1R	0.18
2L	0.28	2R	0.20
3L	0.23	3R	0.12
4L	0.25	4R	0.19
5L	0.28	5R	0.25
6L	0.47	6R	0.19
7L	0.45	7R	0.46
8L	0.46	8R	0.23
Wear Statistics			
Minimum	**Maximum**	**Average**	**Std. Deviation**
0.12	0.47	0.28	0.12

Wear is Measured at Location Shown by Arrow.



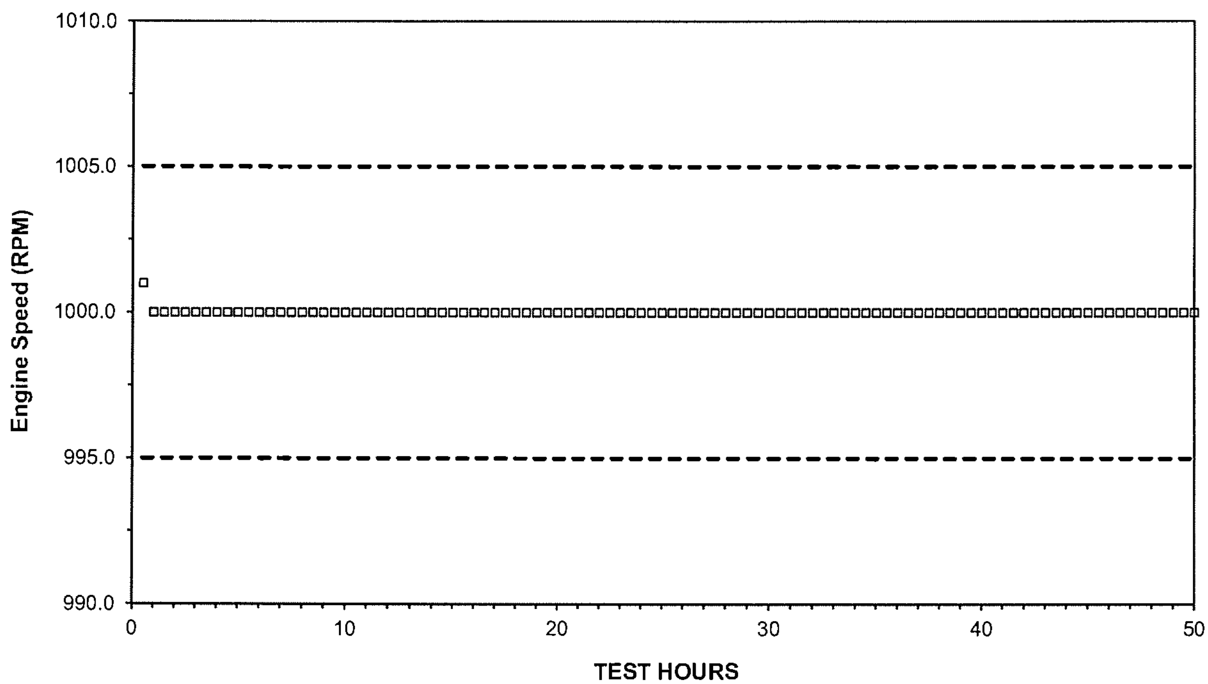
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 3

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

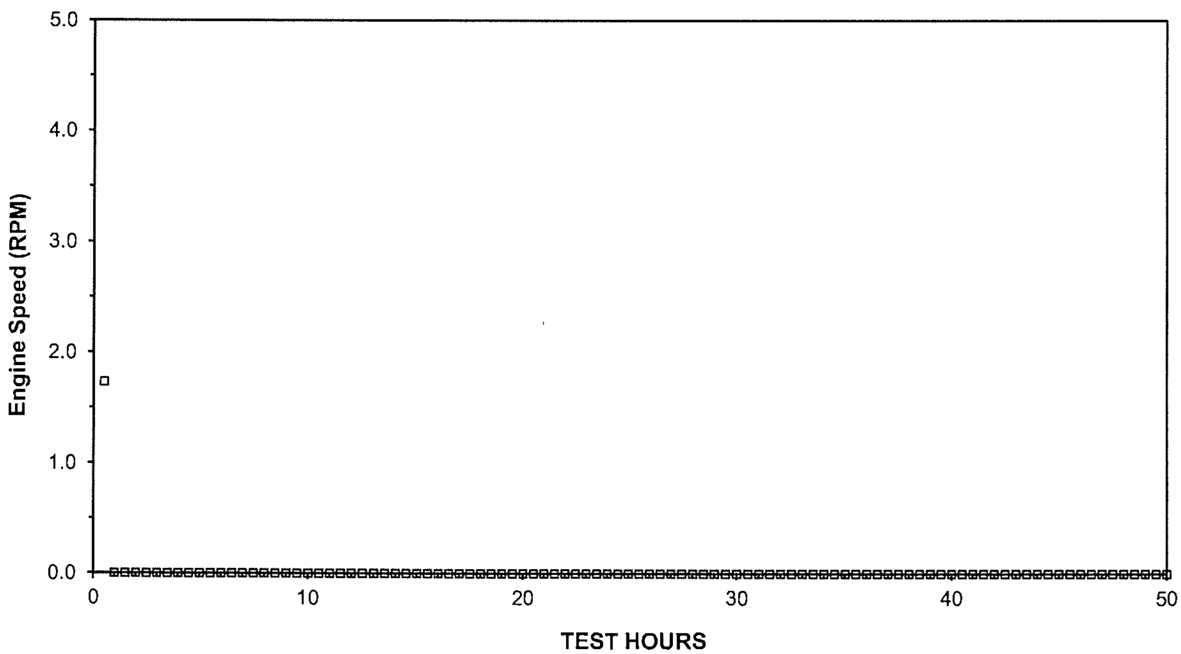
***Test Number Is: Stand - Stand Run No. - Engine No.**

ENGINE SPEED vs TEST HOURS

Process Mean
Xav = 1000.0



Process Variability (s)
Sav = 0.0



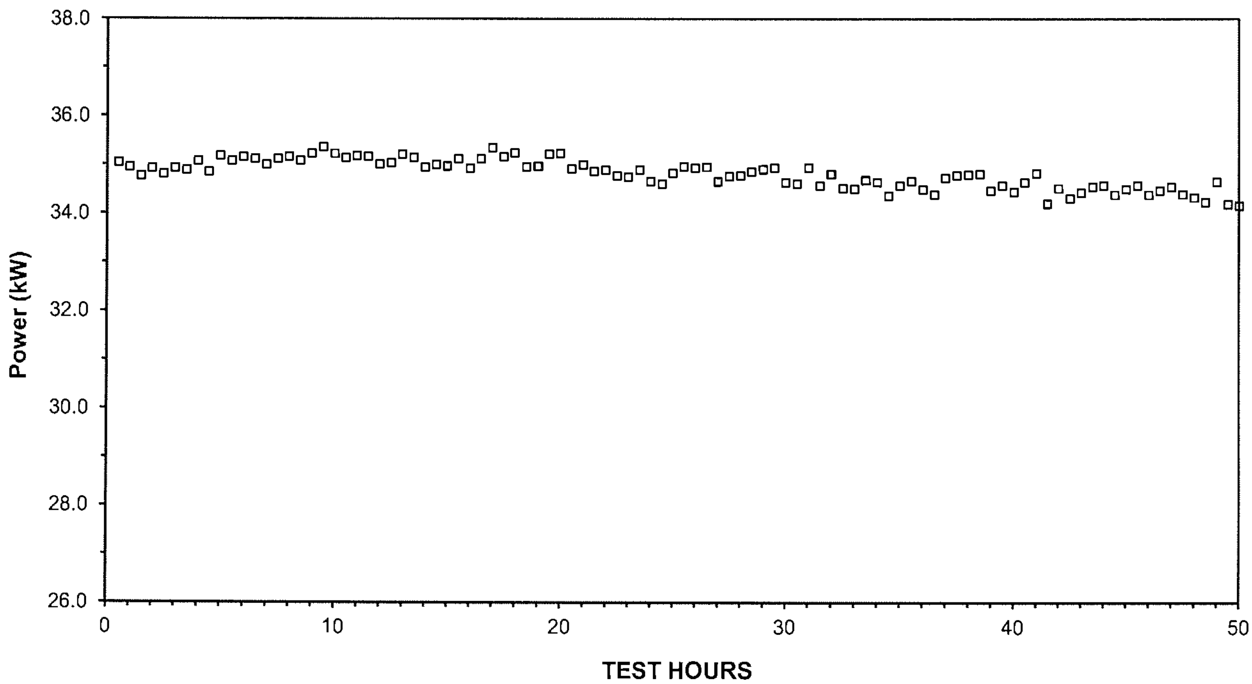
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 4

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

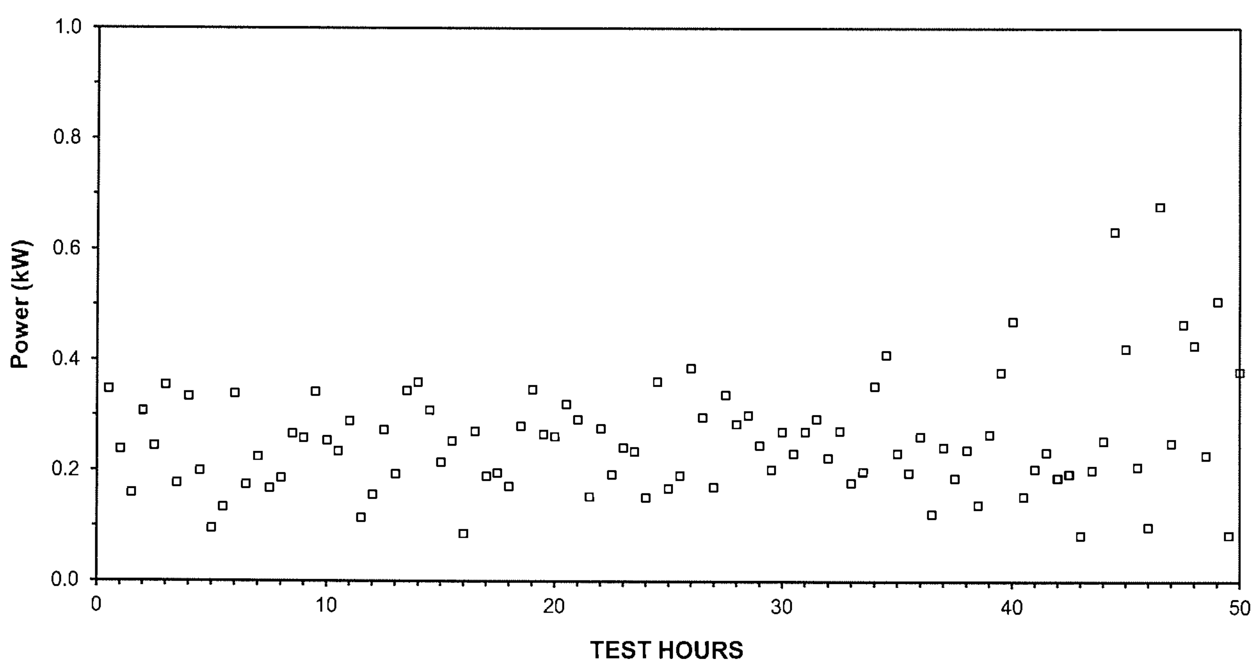
Test Number Is: Stand - Stand Run No. - Engine No.

POWER vs TEST HOURS

Process Mean
Xav = 34.8



Process Variability (s)
Sav = 0.3



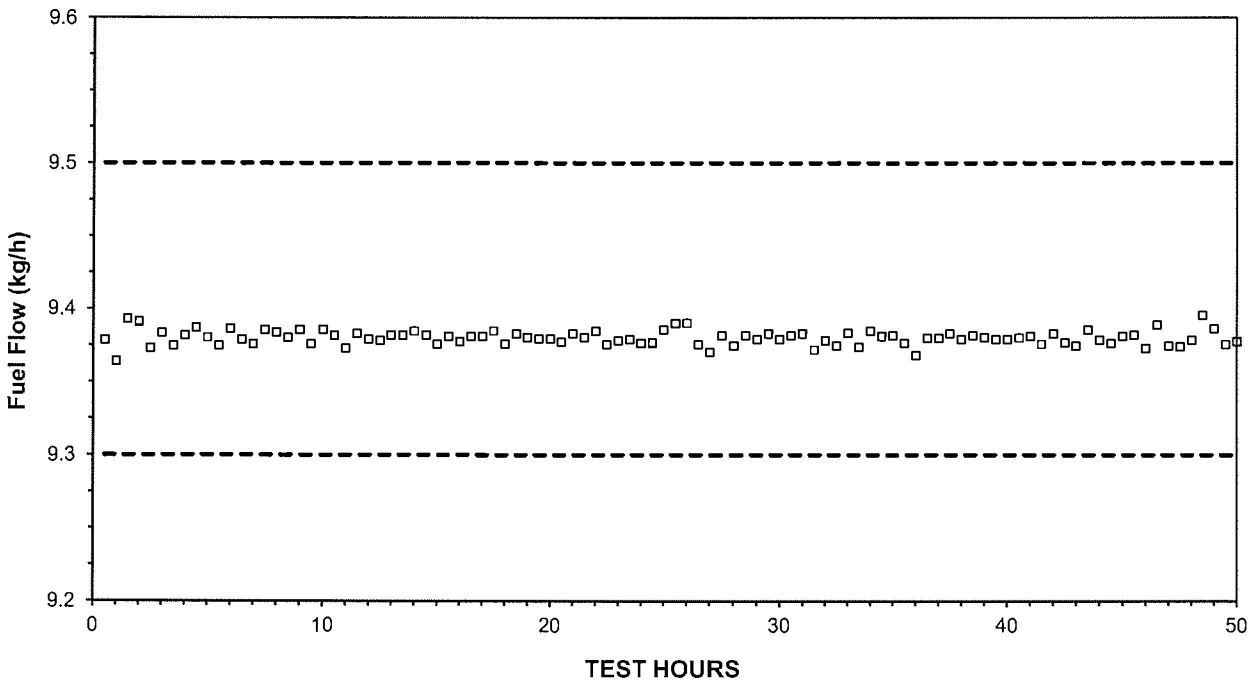
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 5

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

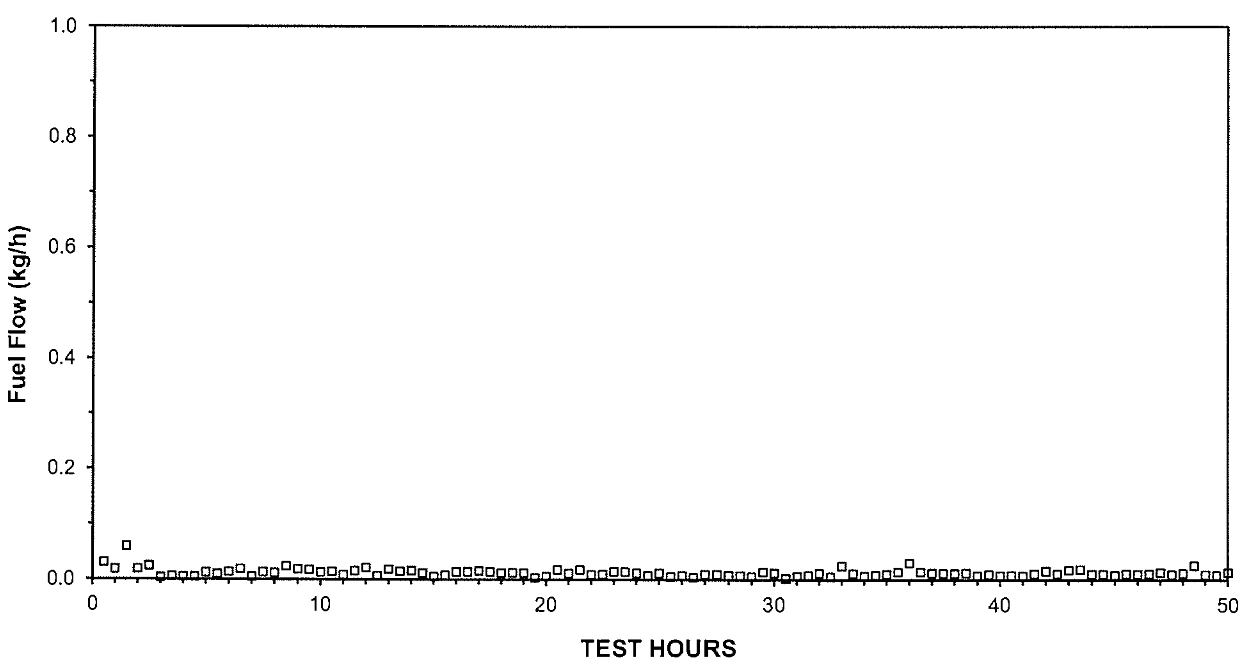
***Test Number Is: Stand - Stand Run No. - Engine No.**

FUEL FLOW vs TEST HOURS

Process Mean
Xav = 9.4



Process Variability (s)
Sav = 0.0



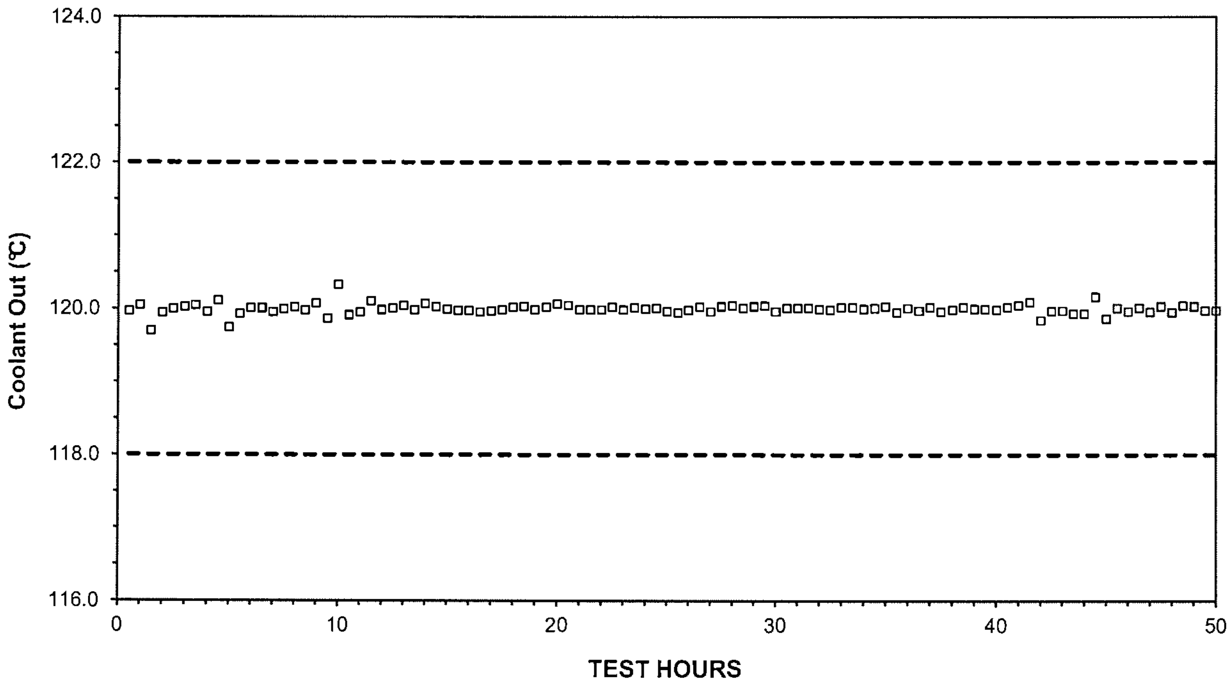
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 6

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

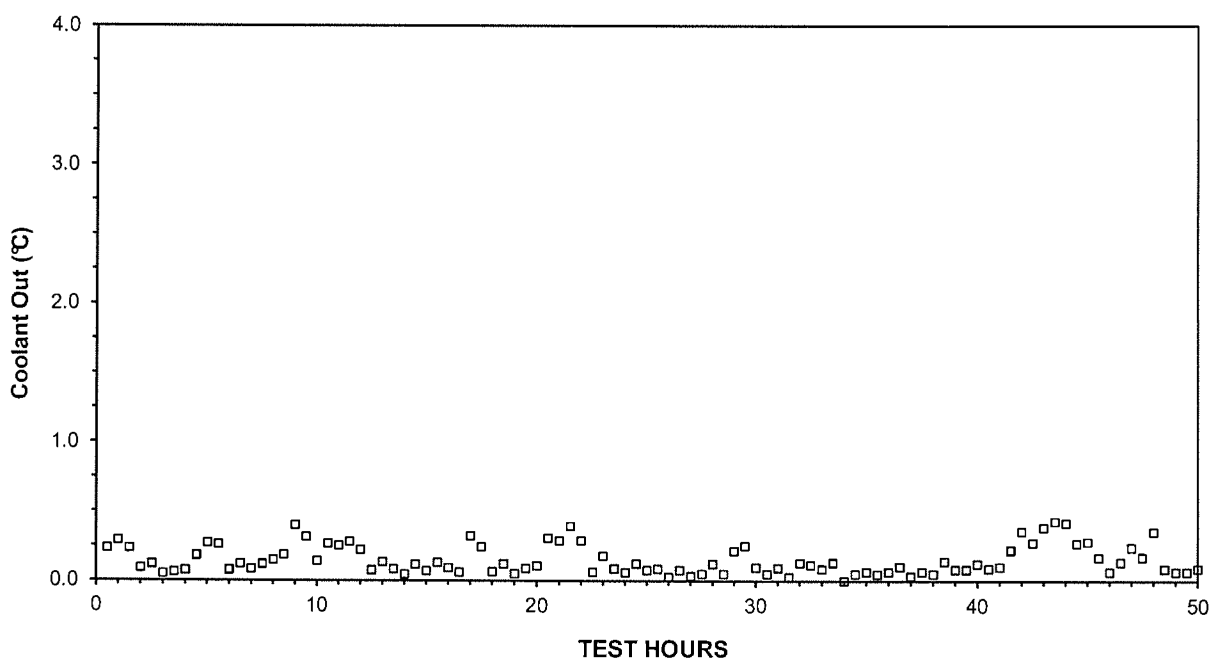
Test Number Is: Stand - Stand Run No. - Engine No.

COOLANT OUT TEMPERATURE vs TEST HOURS

Process Mean
Xav = 120.0



Process Variability (s)
Sav = 0.1



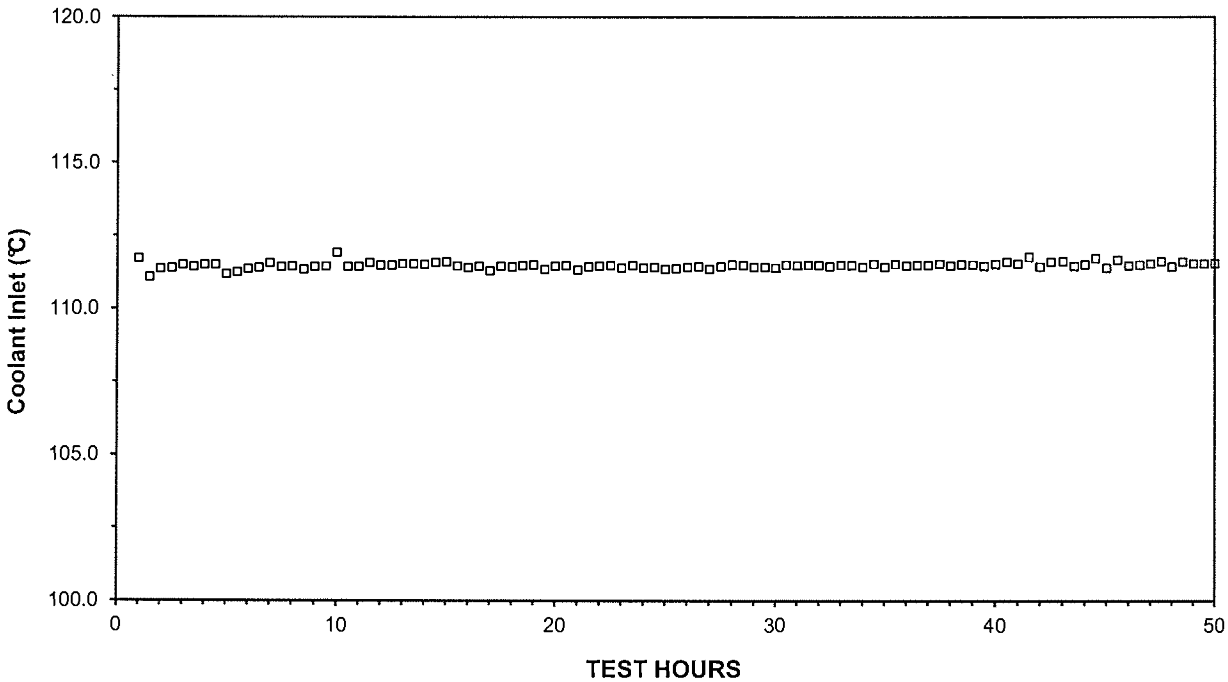
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 7

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

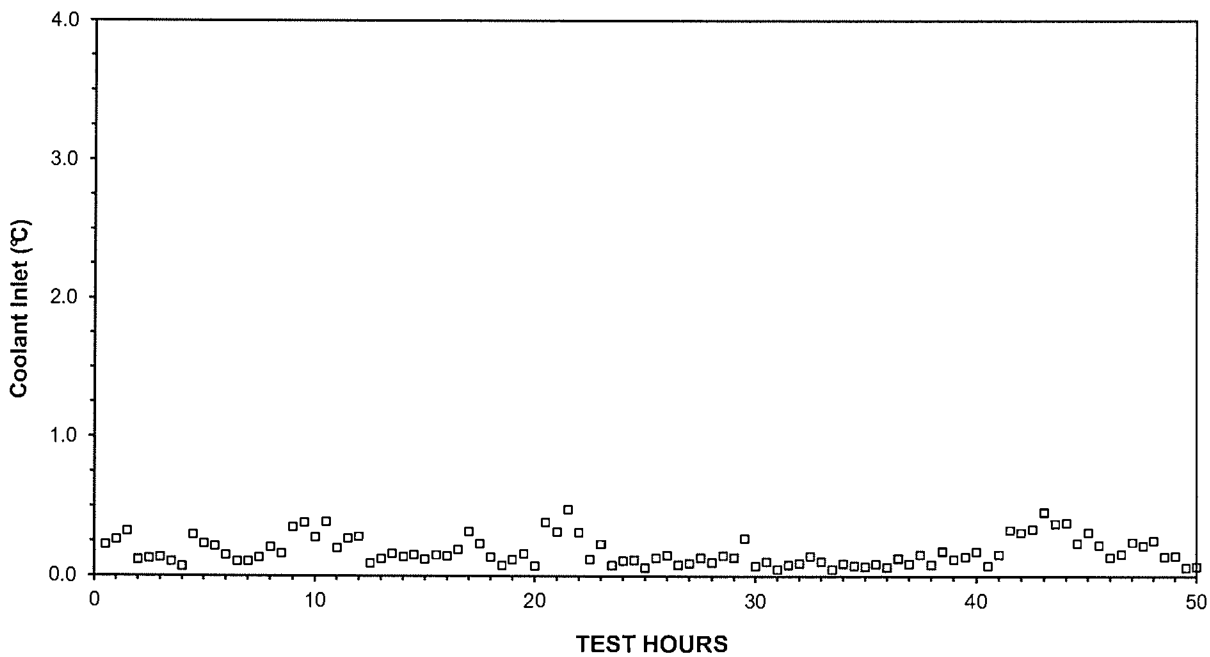
***Test Number Is: Stand - Stand Run No. - Engine No.**

COOLANT INLET TEMPERATURE vs TEST HOURS

Process Mean
Xav = 111.5



Process Variability (s)
Sav = 0.2



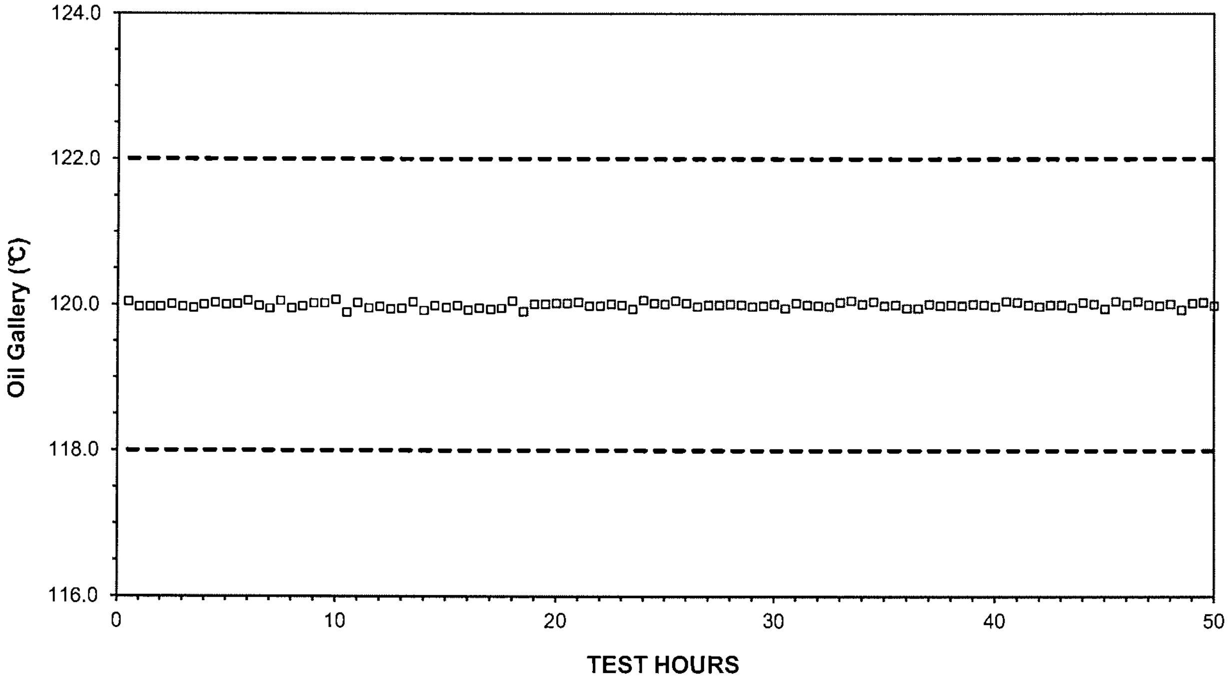
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 8

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

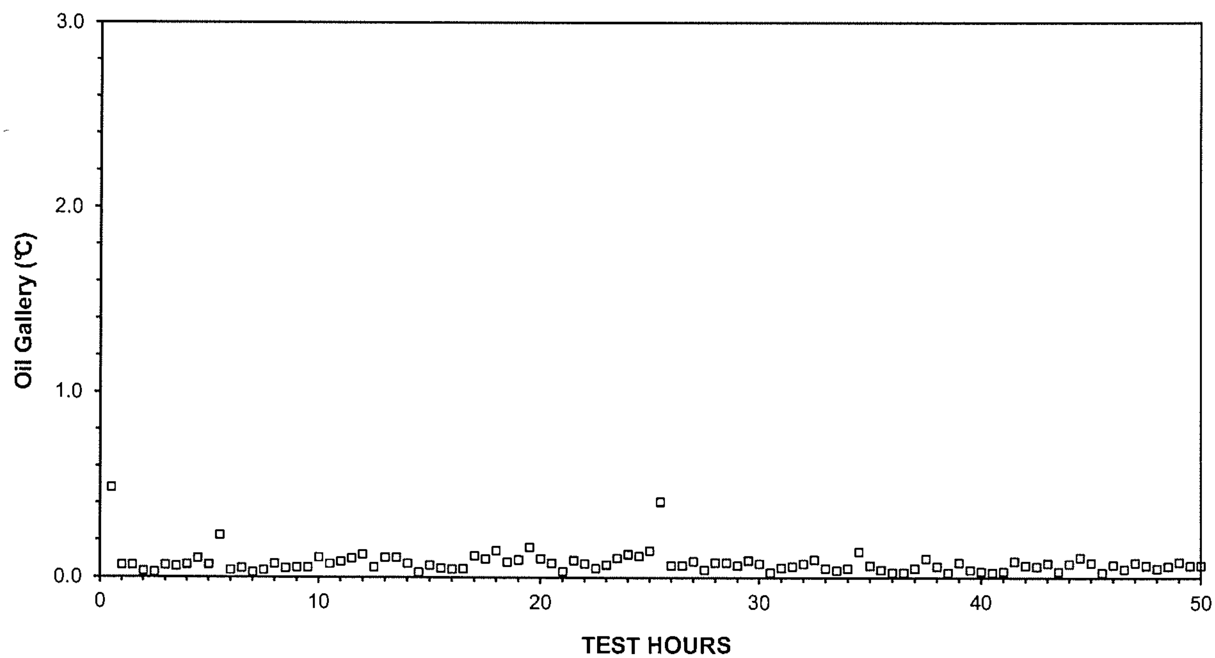
Test Number Is: Stand - Stand Run No. - Engine No.

OIL GALLERY TEMPERATURE vs TEST HOURS

Process Mean
Xav = 120.0



Process Variability (s)
Sav = 0.1



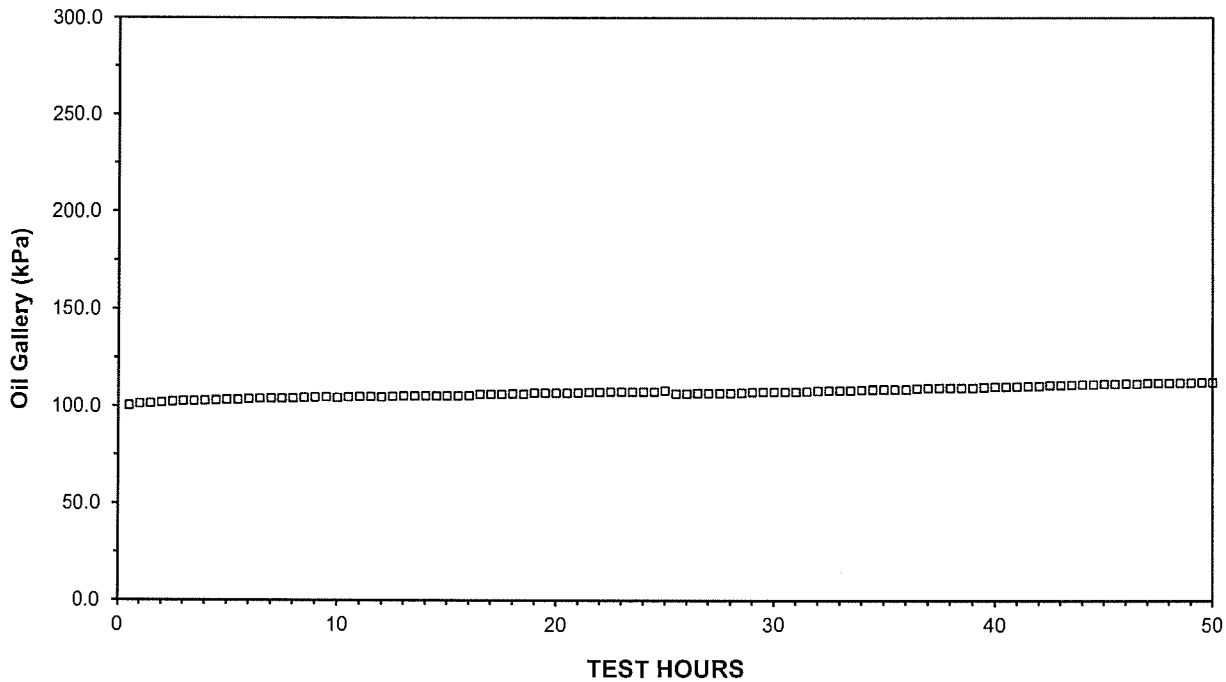
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 9

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

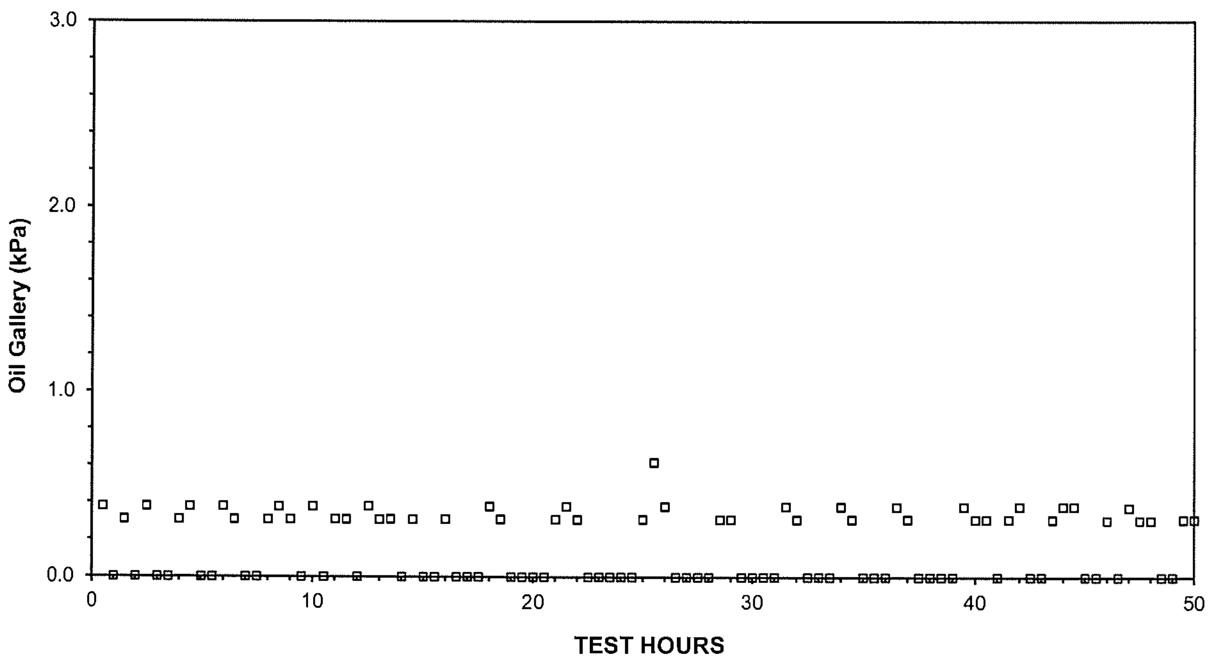
***Test Number Is: Stand - Stand Run No. - Engine No.**

OIL GALLERY PRESSURE vs TEST HOURS

Process Mean
Xav = 107.3



Process Variability (s)
Sav = 0.2



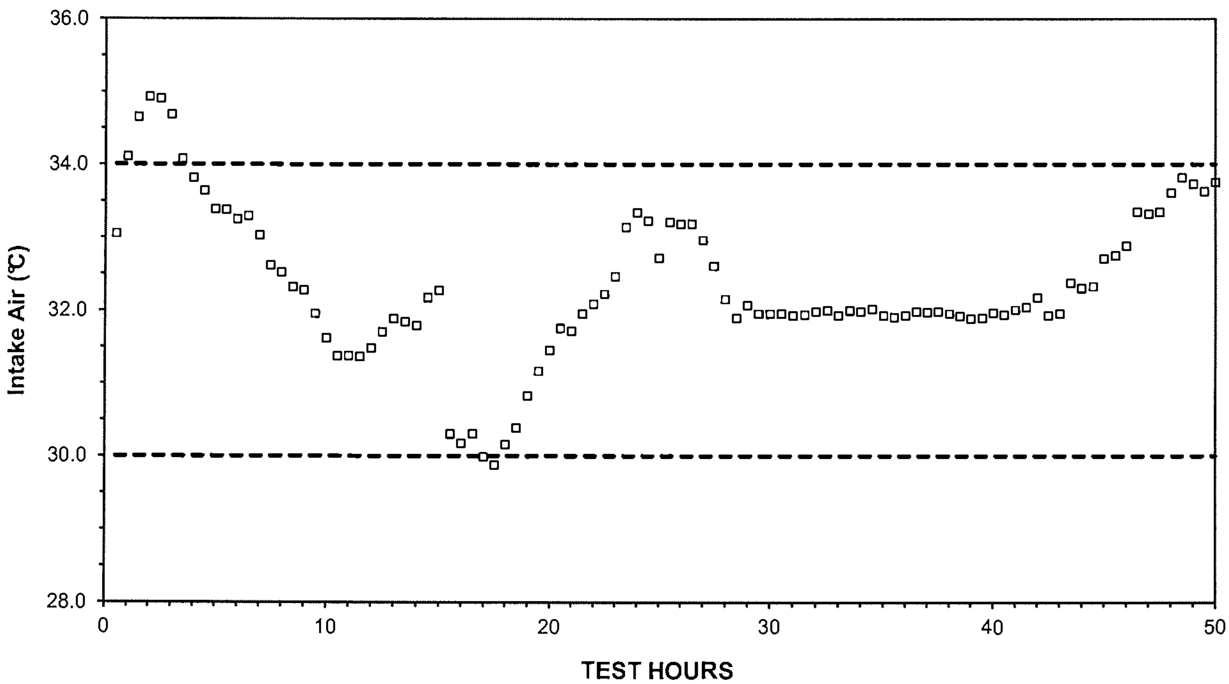
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 10

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

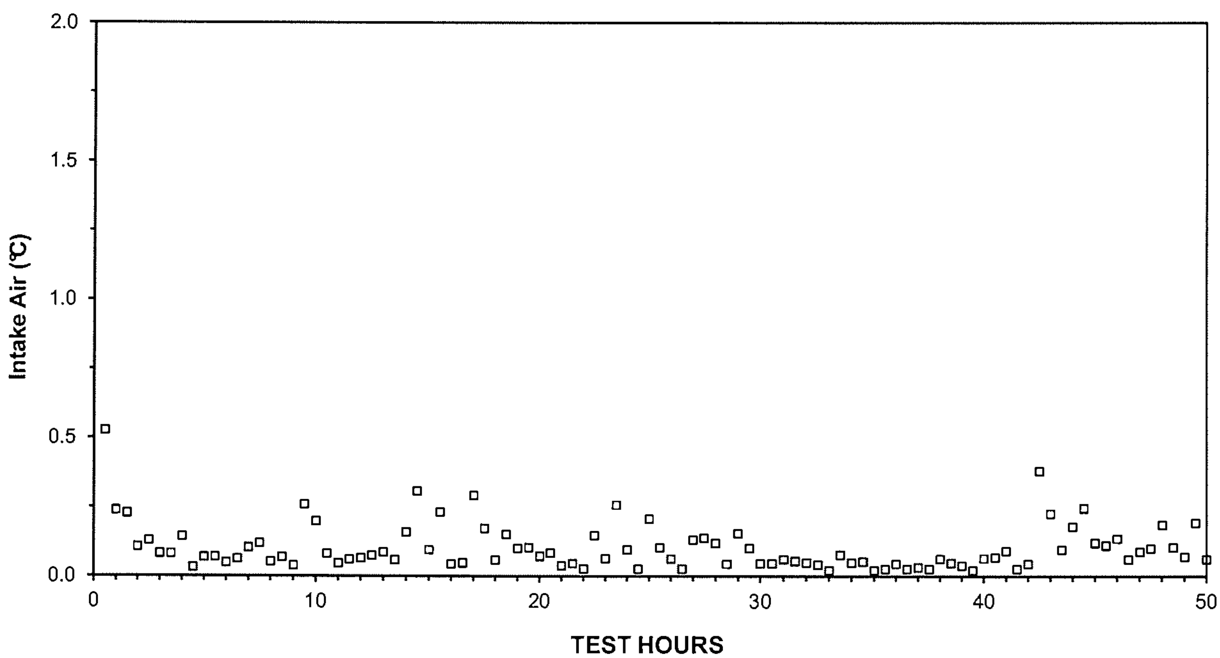
Test Number Is: Stand - Stand Run No. - Engine No.

INTAKE AIR TEMPERATURE vs TEST HOURS

Process Mean
Xav = 32.3



Process Variability (s)
Sav = 0.1



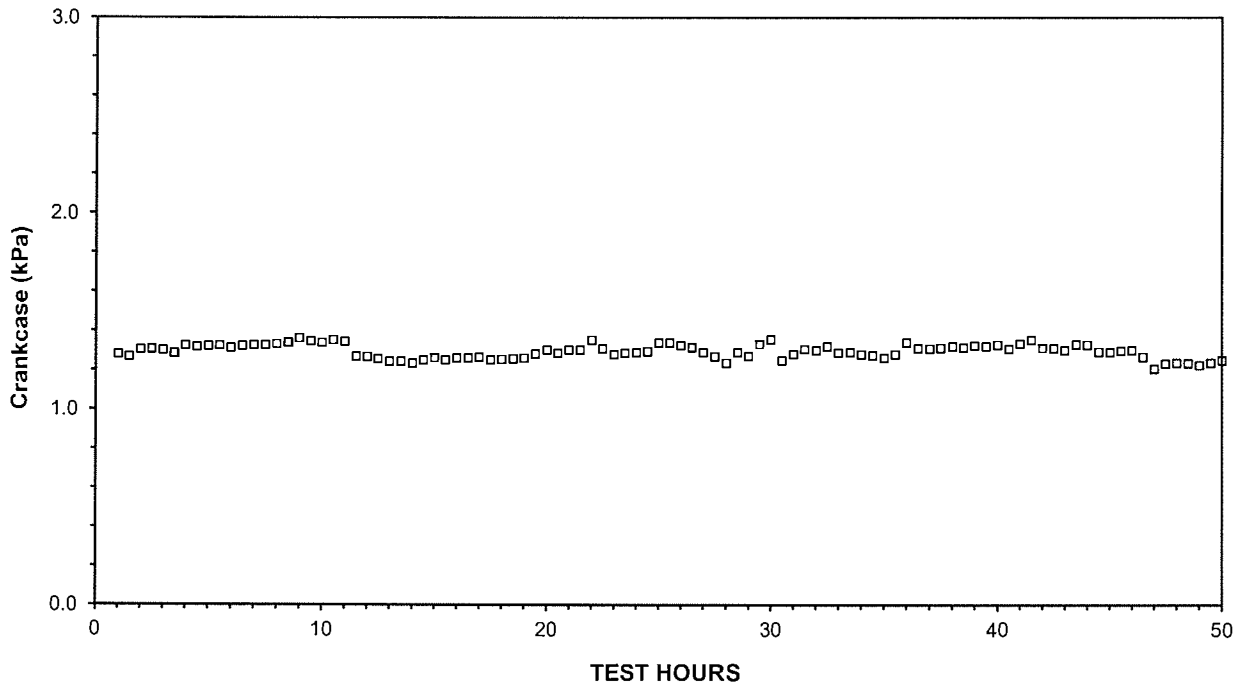
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 11

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

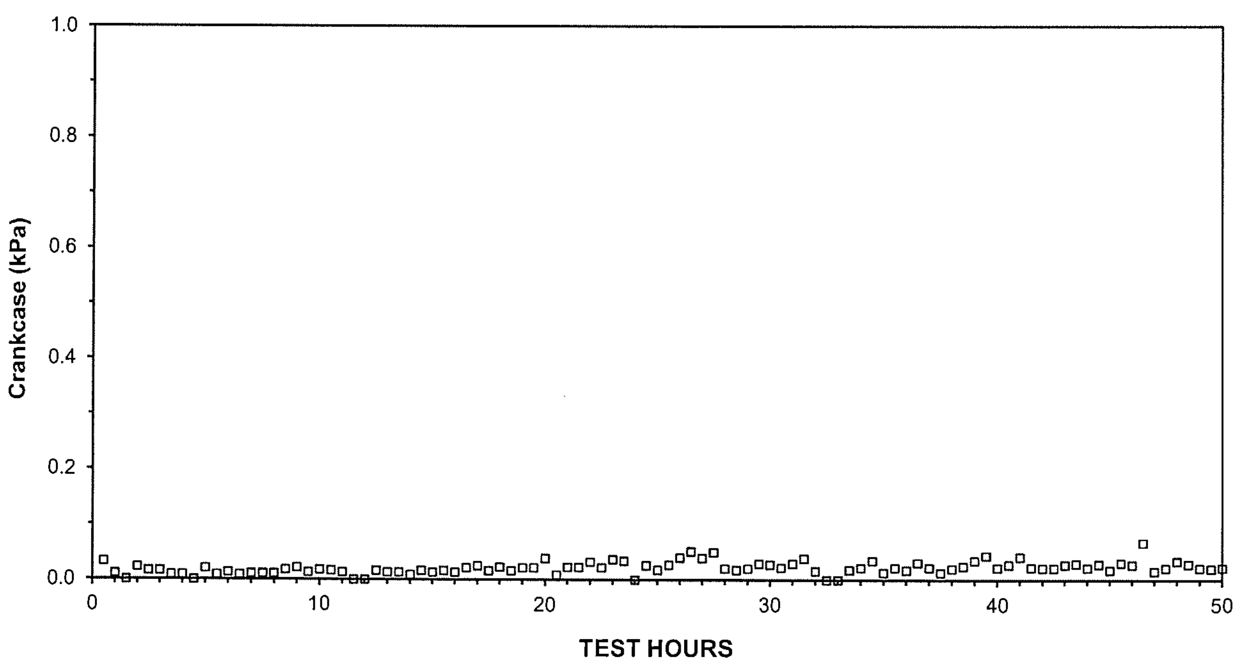
Test Number Is: Stand - Stand Run No. - Engine No.

CRANKCASE PRESSURE vs TEST HOURS

Process Mean
Xav = 1.3



Process Variability (s)
Sav = 0.0



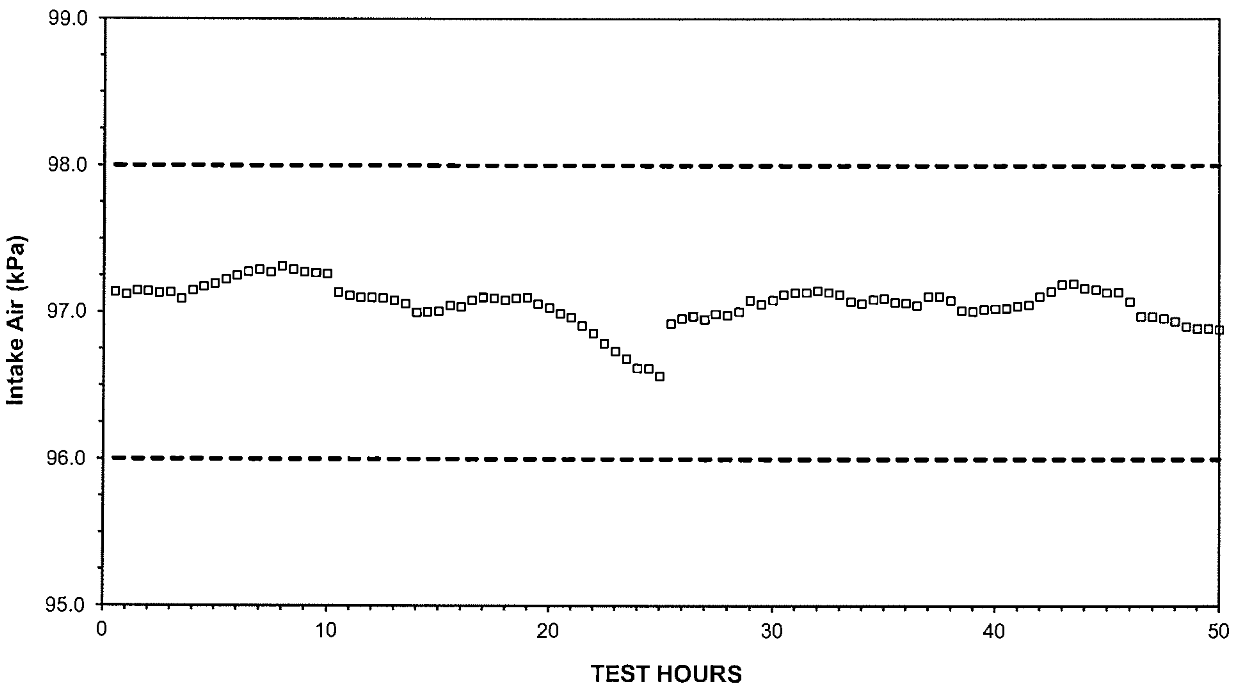
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 12

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

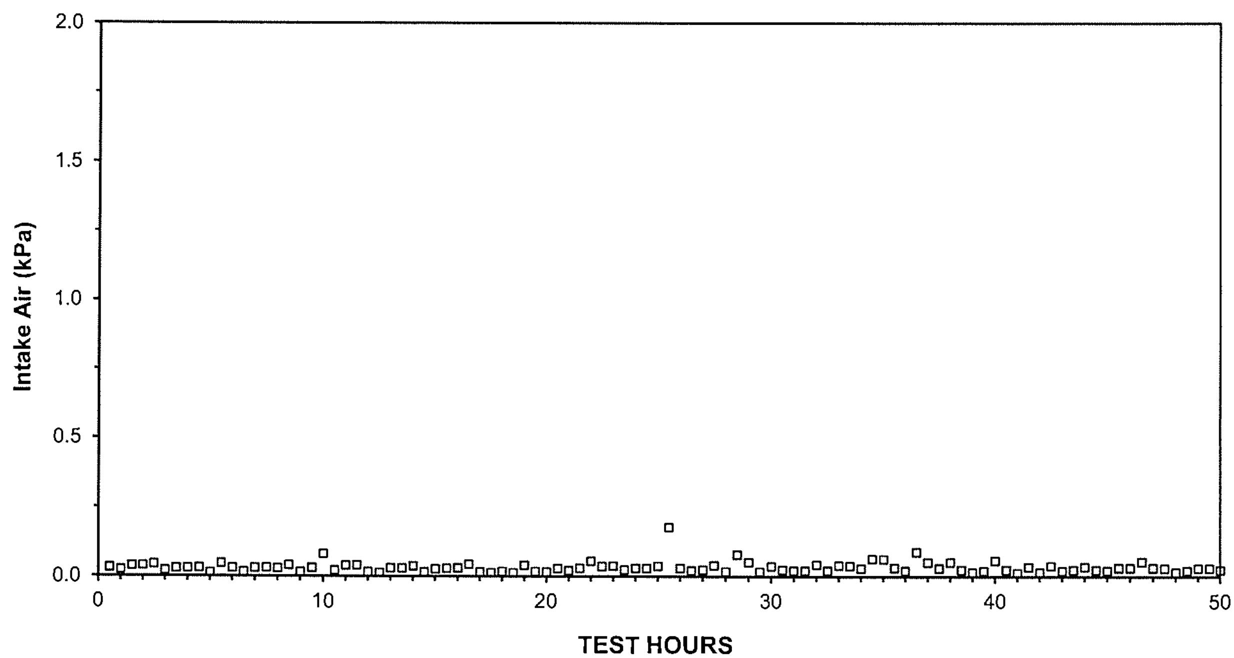
***Test Number Is: Stand - Stand Run No. - Engine No.**

INTAKE AIR PRESSURE vs TEST HOURS

Process Mean
Xav = 97.1



Process Variability (s)
Sav = 0.0

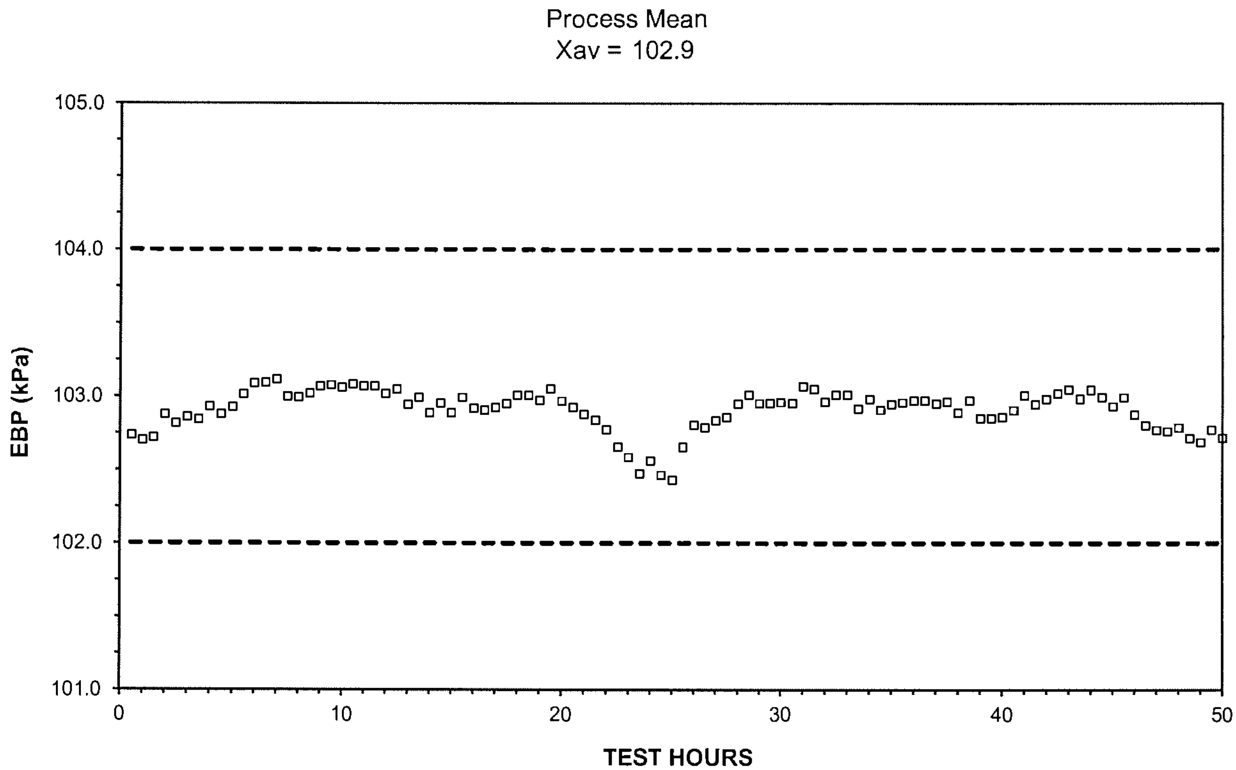


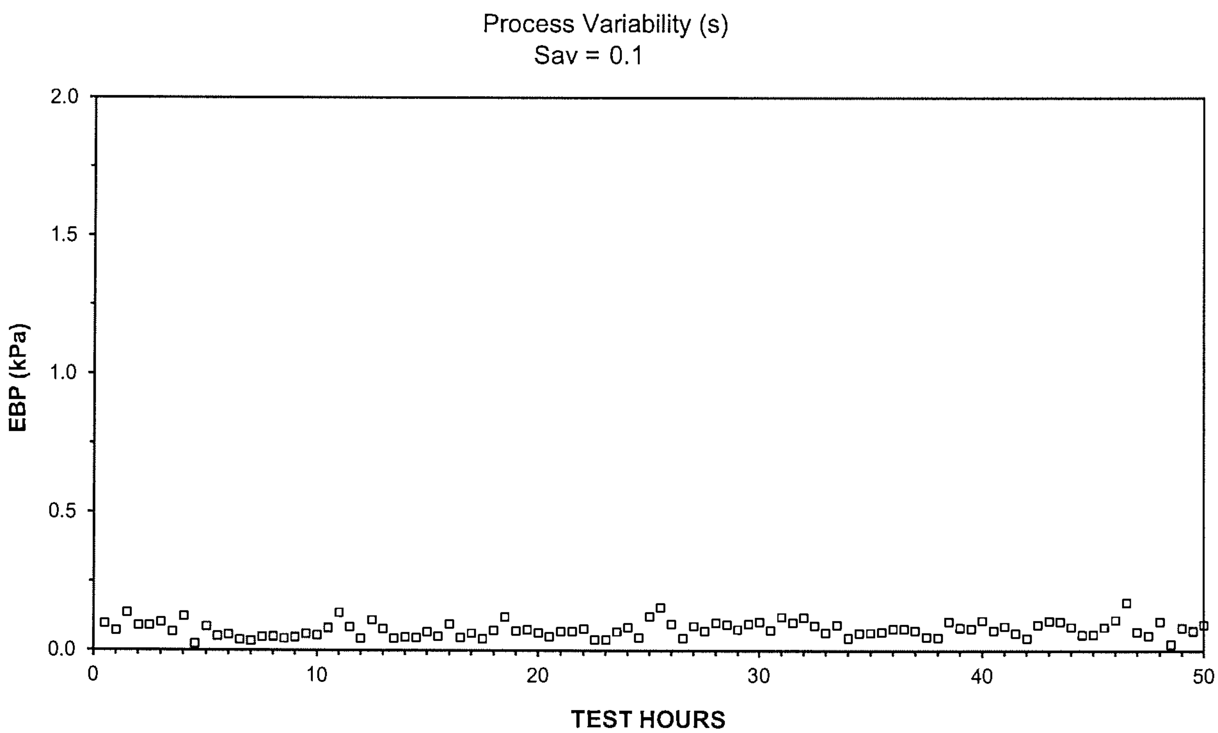
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 13

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

Test Number Is: Stand - Stand Run No. - Engine No.

EXHAUST BACK PRESSURE vs TEST HOURS



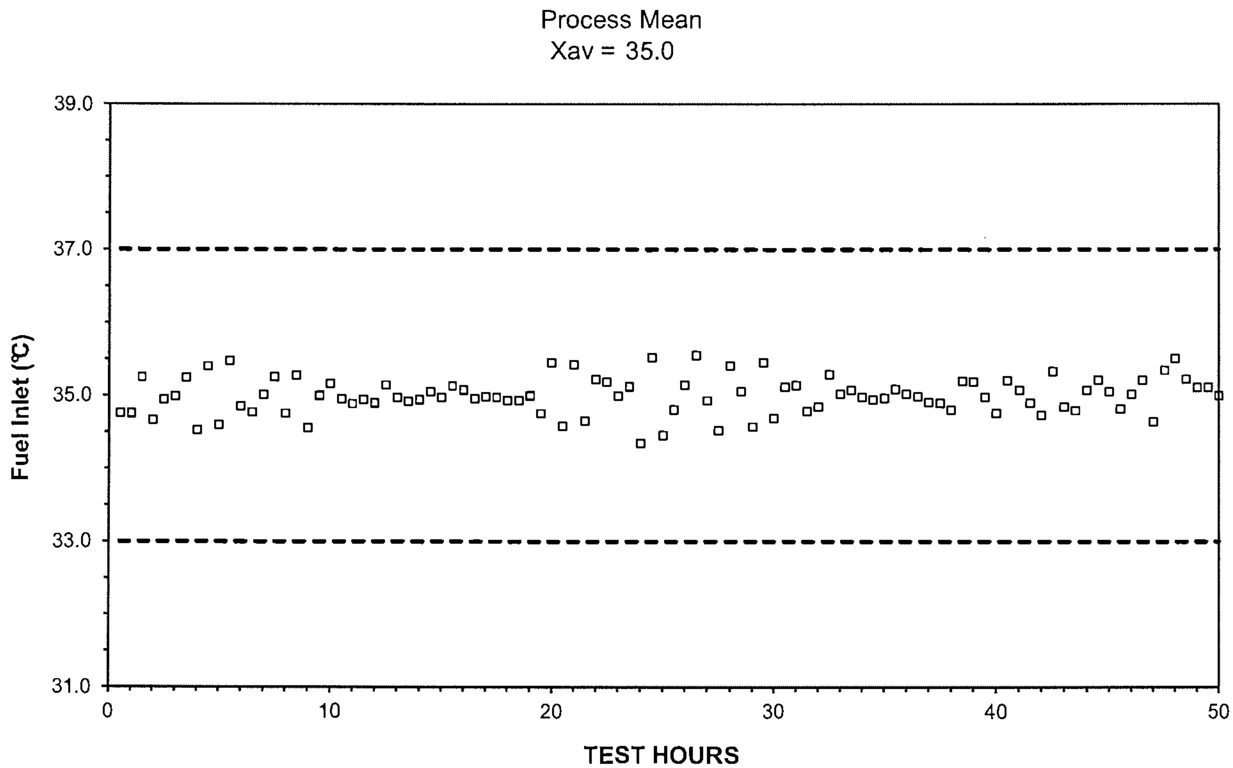


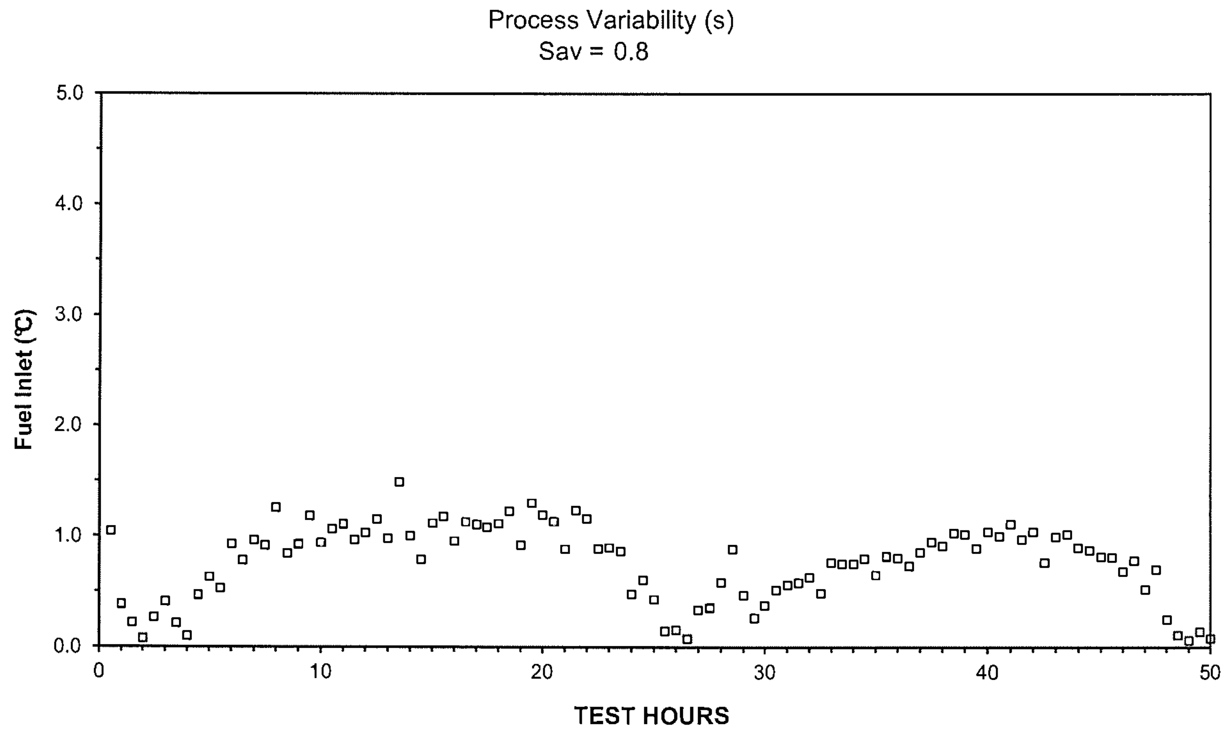
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 14

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

Test Number Is: Stand - Stand Run No. - Engine No.

FUEL INLET TEMPERATURE vs TEST HOURS





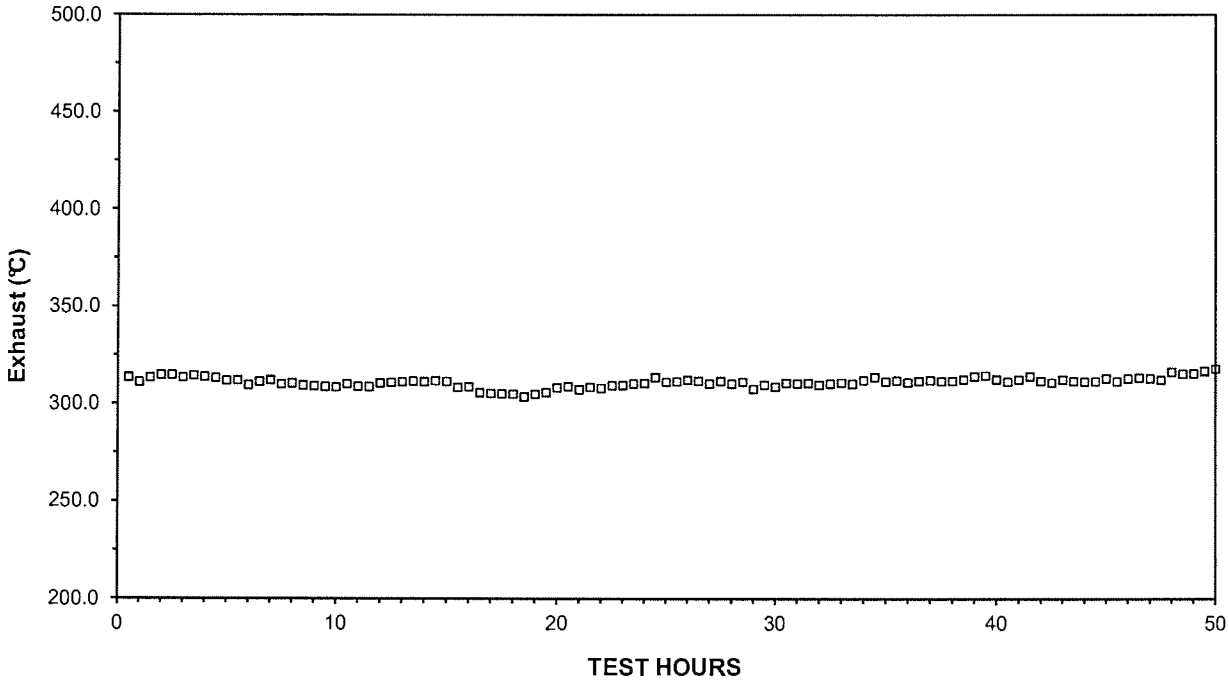
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 15

Laboratory: SR	EOT Date: 20120203
Test Number: 65-404-222-9	
Oil Code: LO-268869	
Formulation/Stand Code:	

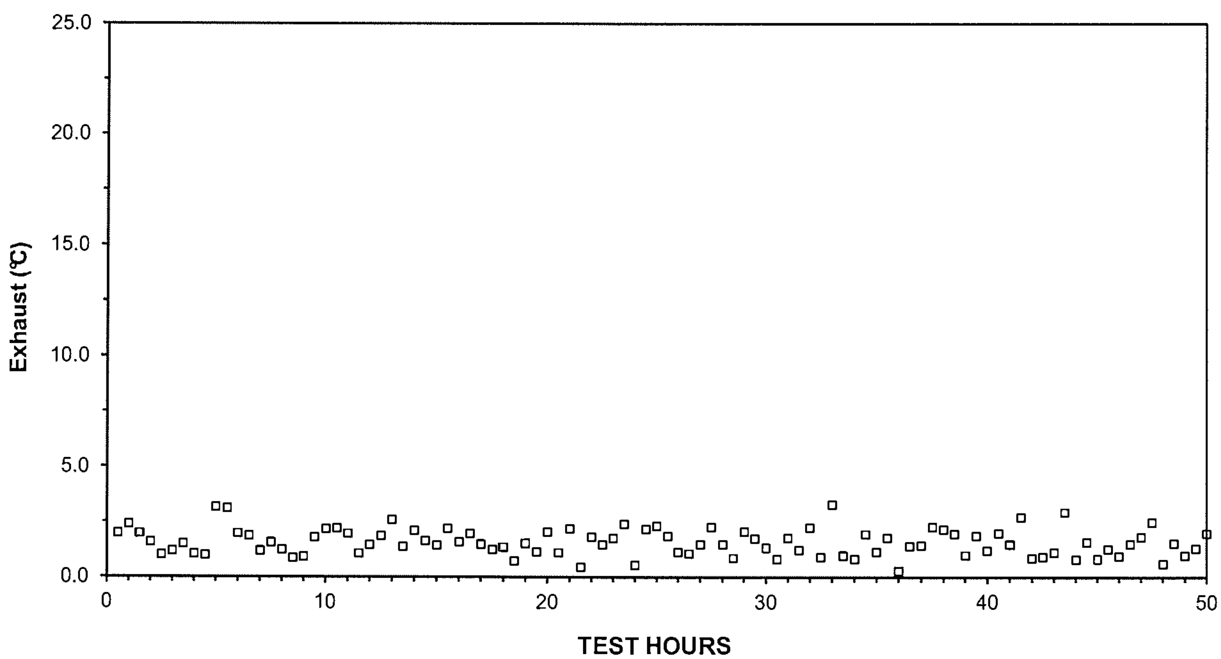
Test Number Is: Stand - Stand Run No. - Engine No.

EXHAUST TEMPERATURE vs TEST HOURS

Process Mean
Xav = 311.0



Process Variability (s)
Sav = 1.6



D 5966
Roller Follower Wear Test
Operational Summary
Form 16

Laboratory: SR	**EOT Date:** 20120203
Test Number: * 65-404-222-9	
Oil Code: LO-268869	
Formulation / Stand Code:	

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Test Parameter	Specification		Average	Std. Dev.	Minimum	Maximum
	6.2L Engine	6.5L Engine				
Engine Speed, r/min	1000 ± 5	1000 ± 5	1000.0	0.1	1000.0	1001.0
Torque, N-m	Record	Record	333.1	2.8	327.0	338.3
Fuel Flow, kg/h	9.0 ± 0.1	9.4 ± 0.1	9.4	0.0	9.4	9.4
Total Oil Consumption, kg	Record	Record	3.9			

Test Parameter	Specification	Average	Std. Dev.	Minimum	Maximum
Coolant Out, °C	120 ± 2	120.0	0.1	119.7	120.3
Coolant In, °C	Report Only	111.5	0.1	111.1	111.9
Main Oil Gallery, °C	120 ± 2	120.0	0.0	119.9	120.1
Fuel In, °C	35 ± 2	35.0	0.3	34.4	35.6
Intake Air, °C	32 ± 2	32.3	1.0	29.9	34.9
Oil Sump, °C	Report	128.2	0.2	127.8	128.7
Exhaust, °C	Report	311.0	2.6	303.6	317.9

Pressures	Specification	Average	Std. Dev.	Minimum	Maximum
Crankcase, kPa	Report	1.3	0.0	1.4	1.2
Back Pressure, kPa	103 ± 1	102.9	0.1	102.4	103.1
Intake Air, kPa	97 ± 1	97.1	0.1	96.6	97.3

D 5966
Roller Follower Wear Test
Oil Analysis
Form 17

Laboratory: SR	EOT Date: 20120203
Test Number: * 65-404-222-9	
Oil Code: LO-268869	
Formulation / Stand Code:	

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Hours	Viscosity, cSt @ 100°C	% SOOT
NEW	8.80	0.2
025	10.90	2.5
050	12.07	4.4

Hours	Elements						
	Al	Cr	Cu	Fe	Pb	Si	Sn
NEW	6	0	0	2	0	2	0
025	6	2	3	100	5	5	2
050	7	4	4	202	9	6	3

Average Bosch Smokes	6.5
Average BSFC	0.270 kg/kW-h

D 5966
Roller Follower Wear Test
Unscheduled Downtime & Maintenance Summary
Form 18

Laboratory: SR	**EOT Date:** 20120203
Test Number: * 65-404-222-9	
Oil Code: LO-268869	
Formulation / Stand Code:	

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Number of Downtime Occurrences: 0

Test	Date	Downtime	Reasons
Total Downtime		0:00	

Other Comments

Number of Comment Lines: 0

D 5966
Roller Follower Wear Test
Test Fuel Analysis (Last Batch)
Form 21

Laboratory: SR	**EOT Date:** 20120203
Test Number: * 65-404-222-9	
Oil Code: LO-268869	
Formulation / Stand Code:	
Supplier:	**Batch Identifiers:** 11JPPC901

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Measurement	Specifications	Analysis	Test Method
Total Sulfur, % Weight	0.03 - 0.05	0.04	D 2622
Gravity, °API	32 - 36	35.1	D 287
Hydrocarbon Composition			
Aromatics, % Vol.	28 - 35	30.7	D 5186
Olefin	Report	4.3	D 1319
Saturates	Report	65.0	D 1319
Cetane Index	42 - 48	44.0	D 4737
Cetane No.	42 - 48	46.0	D 613
Copper Strip Corrosion	3 Maximum	1A	D 130
Flash Point, °C	54 Minimum	63	D 92
Cloud Point, °C	-12 Maximum	-21	D 2500
Pour Point, °C	-18 Maximum	-27	D 97
Carbon Residue on 10% Residuum, %	0.35 Maximum	0.10	D 524 (10% Bottoms)
Water & Sediment, % Vol.	0.05 Maximum	0.00	D 2709
Ash, % Wgt.	0.01 Maximum	0.000	D 482
Viscosity, cSt @ 40°C	2.0 - 3.2	2.4	D 445
Distillation, °C			
IBP	177 - 199	173	D 86
10%	210 - 232	206	D 86
50%	249 - 277	252	D 86
90%	299 - 327	326	D 86
EP	327 - 360	361	D 86

D 5966
Roller Follower Wear Test
Characteristics of the Data Acquisition System
Form 22

Laboratory: SR	EOT Date: 20120203
Test Number: * 65-404-222-9	
Oil Code: LO-268869	
Formulation / Stand Code:	

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Parameter (1)	Sensing Device (2)	Calibration Frequency (3)	Record Device (4)	Observation Frequency (5)	Record Frequency (6)	Log Frequency (7)	System Response (8)
Temperatures							
Main Oil G.	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Fuel In.	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Intake Air	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Oil Sump	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Exhaust	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Coolant Out	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Other							
Fuel Flow	Mass Flow	Every ref test	C/D	0	0	1 per min	2.5s
Engine RPM	Magnetic	Every ref test	C/D	0	0	1 per min	0.5s
Load	Strain Gage	Every ref test	C/D	0	0	1 per min	0.5s
Intake Press.	Mechanical	Every ref test	C/D	0	0	1 per min	N/A
Exhaust Press.	Mechanical	Every ref test	C/D	0	0	1 per min	N/A
Oil Gallery Press.	Mechanical	Every ref test	C/D	0	0	1 per min	N/A

Legend:

(1) Operating Parameter
(2) The Type of Device Used to Measure Temperature, Pressure or Flow
  T/C - Thermocouple
(3) Frequency at Which the Measurement System is Calibrated
(4) The Type of Device Where Data is Recorded
  LG - Handlog Sheet
  DL - Automatic Data Logger
  SC - Strip Chart Recorded
  C/M - Computer, Using Manual Data Entry
  C/D - Computer, Using Direct I/O Entry
(5) Data are Observed but Only if Recorded Off Spec.
(6) Data are Recorded but are not Retained at EOT
(7) Data are Logged as Permanent Record, Note Specify if:
  SS - Snapshot Taken at Specified Frequency
  AG/X Average of X Data Points at Specified Frequency
(8) Time for the Output to Reach 63.2% of Final Value for Step Change at Input

D5966
Roller Follower Wear Test

Laboratory: SR	**EOT Date:** 20120203
Test Number: * 65-404-222-9	
Oil Code: LO-268869	
Formulation / Stand Code:	

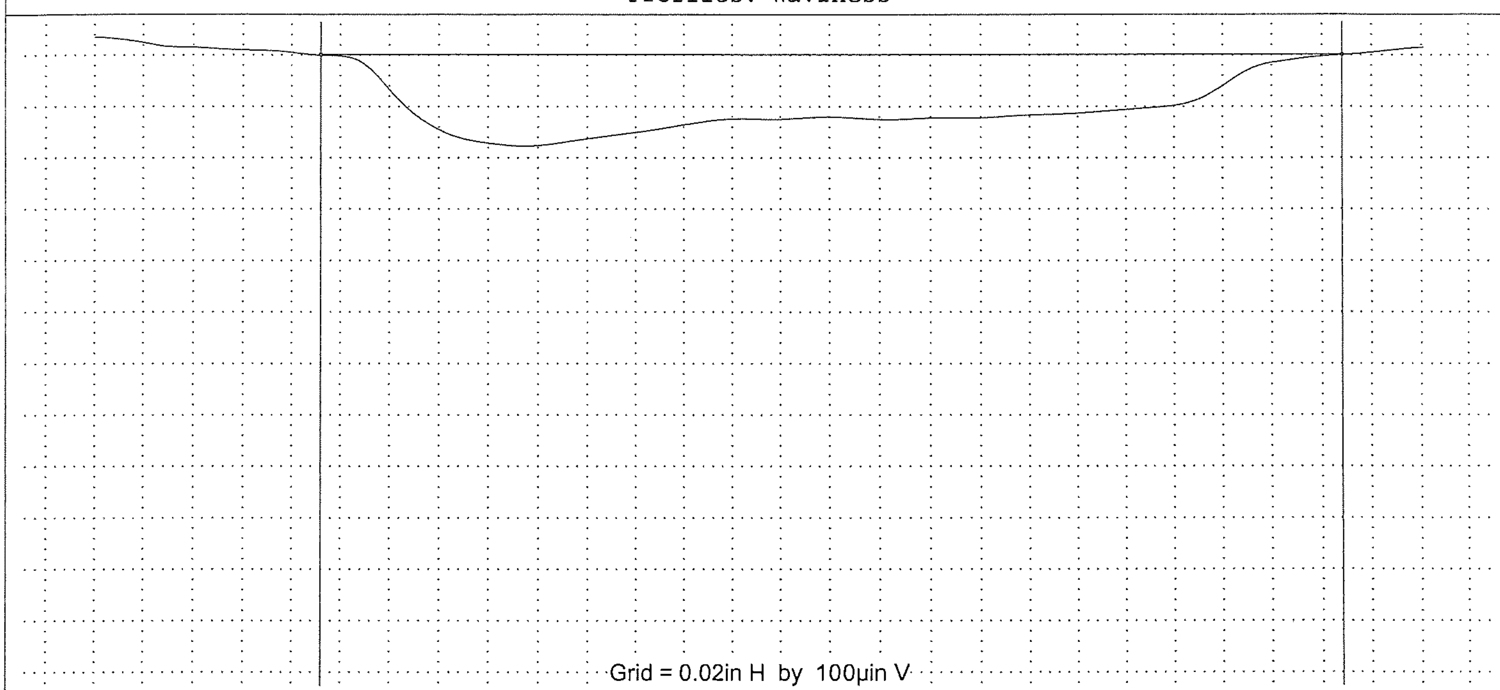
**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Appendix A

Roller Follower Wear Test Traces

1. Profilometer Traces 1-8 (Right and Left) (8 pages)

Profiles: Waviness



Settings

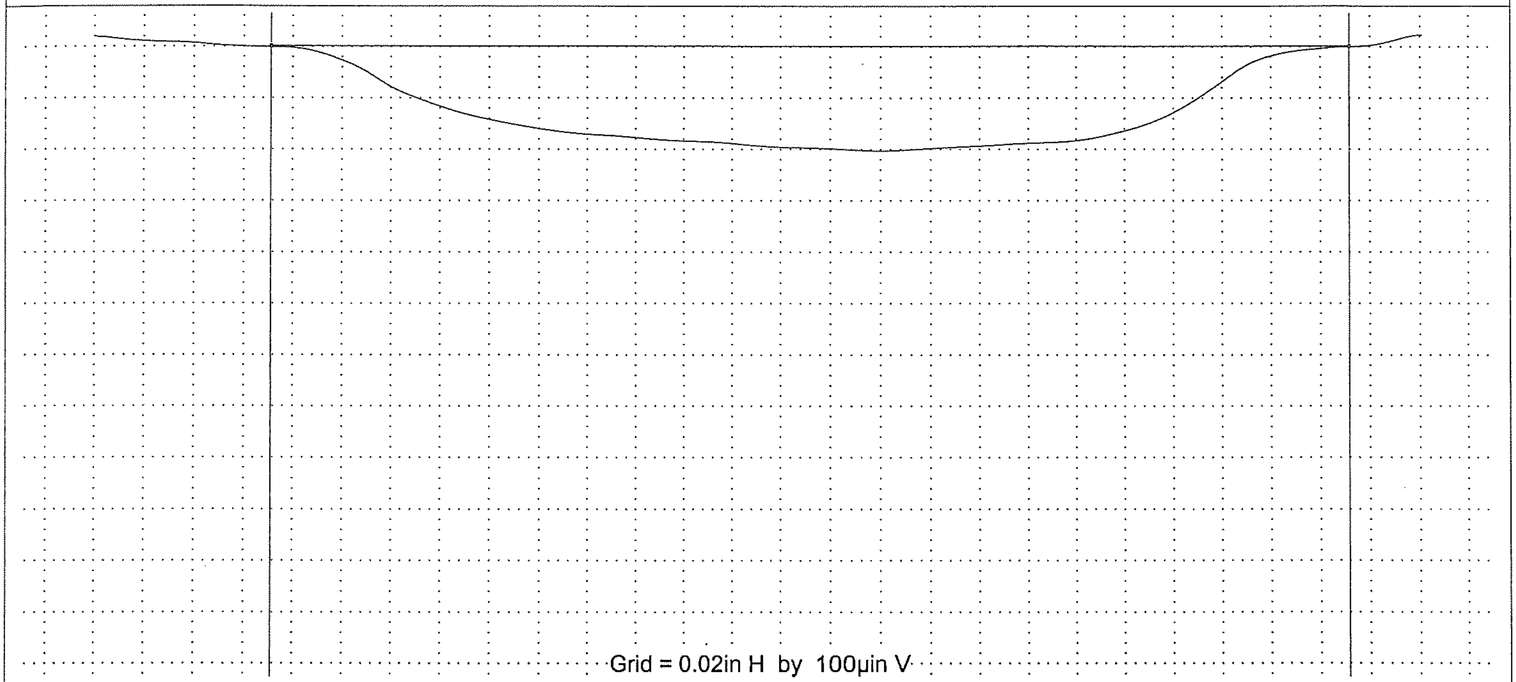
Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:29 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R1
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	177.4	µin

Waviness Parameters:

Profiles: Waviness



Settings

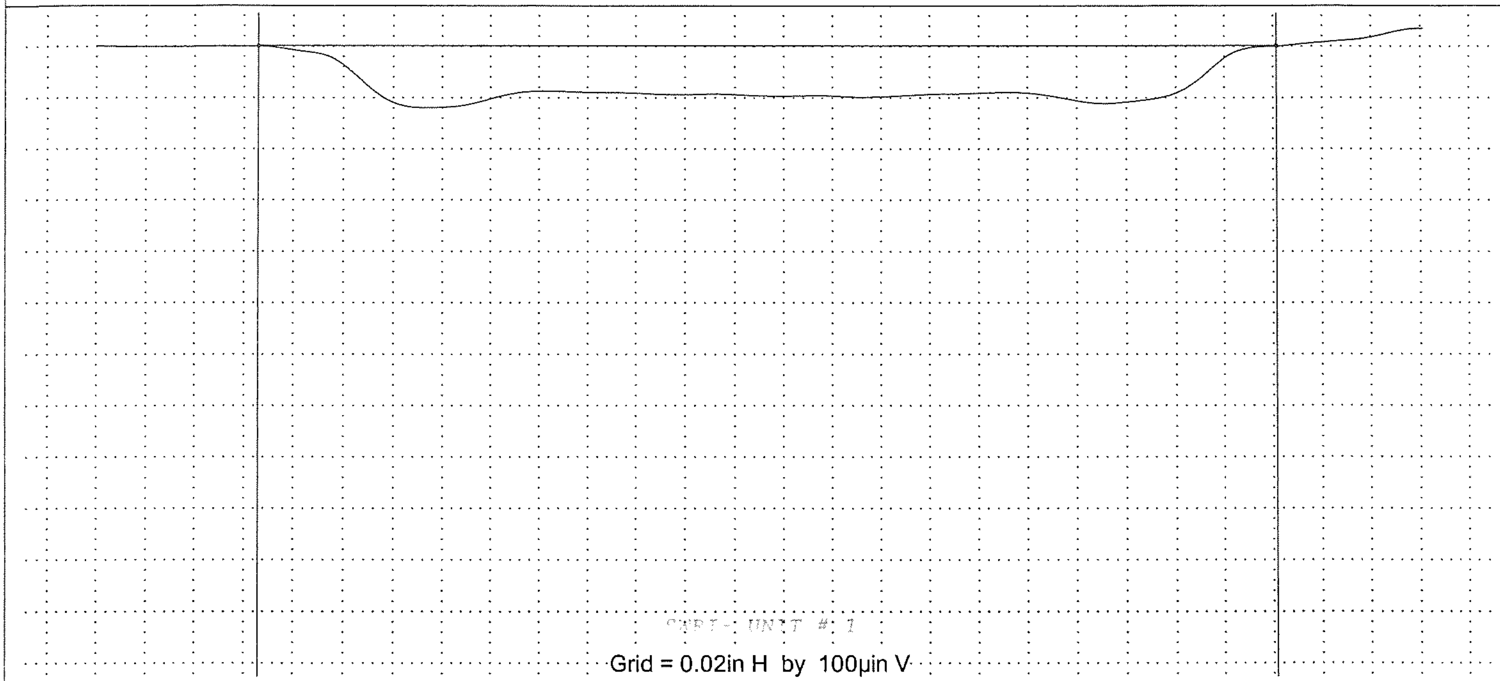
Software: 2.46; Advanced; 3.95
Data
Collected: Mon Feb 06 09:31 2012
By: Kerry McCubbin
At: SWRI- UNIT # 1
Tracer Used: PDT-2-522
Sampled Length: 0.541 in
Sample Spacing: 18.9 µin
Description
RFWT, Pin R2
Run 65-404-222-9
File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
Name: MicroAnalyzer 2000
Serial #: S-2000-3027
Current Tracer:PDT-2-522
Travel Distance: 0.541 in
Trace Velocity: 0.030 in/s
Form
Form Type: Two-Point Line
Roughness Filter
Type: Gaussian
Cutoff: 0.030 in
No Filter Width Removal at Ends
Parameter Calculation Settings
Peak Count Threshold: 19.7 µin
High Spot Count Threshold: 19.7 µin
tp Reference Percent: 5 %
tp Slice Depth: 19.7 µin
Short Wavelength Filter
Type: Gaussian
Cutoff: 0.0001 in
Waviness Filter
Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	203.2	µin

Instrument

Profiles: Waviness



Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:33 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R3
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.P
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

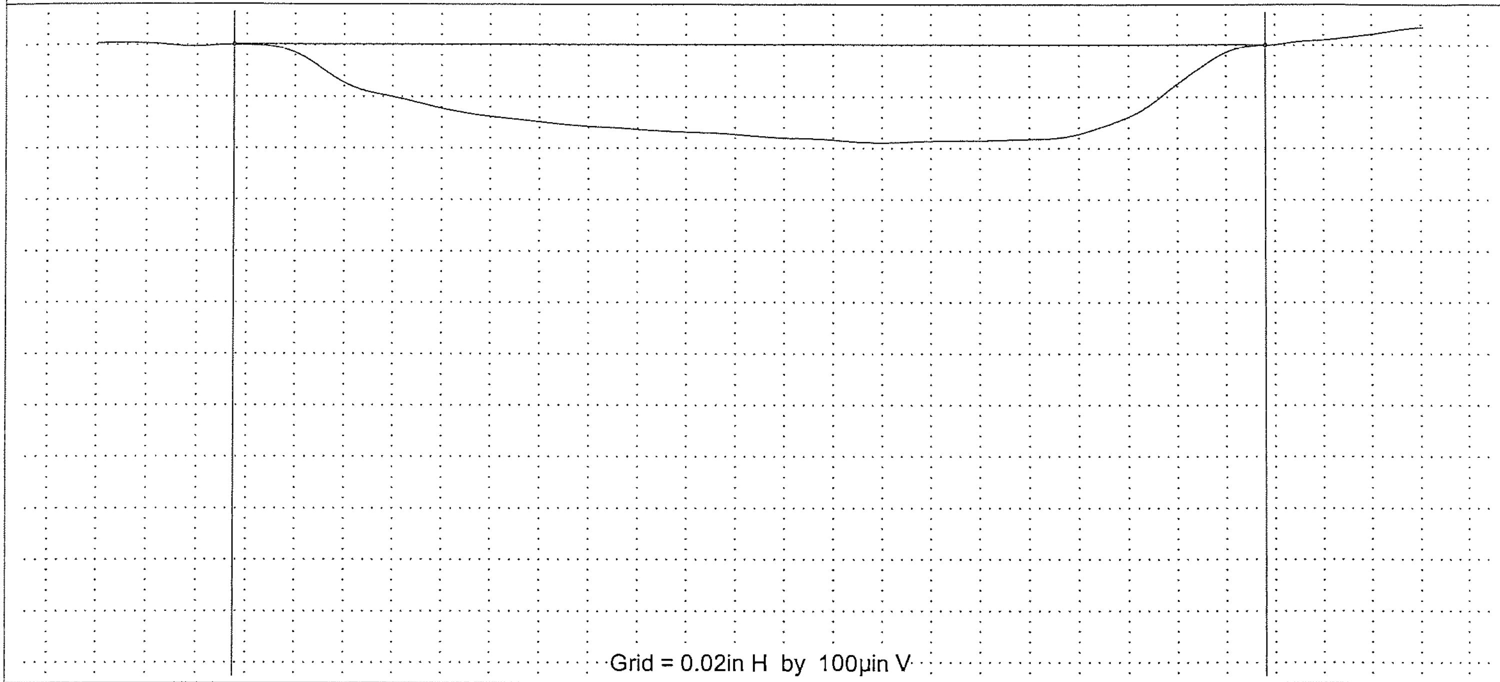
Run 65-404-222-9

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	119.9	µin

Parameters

Profiles: Waviness



Settings

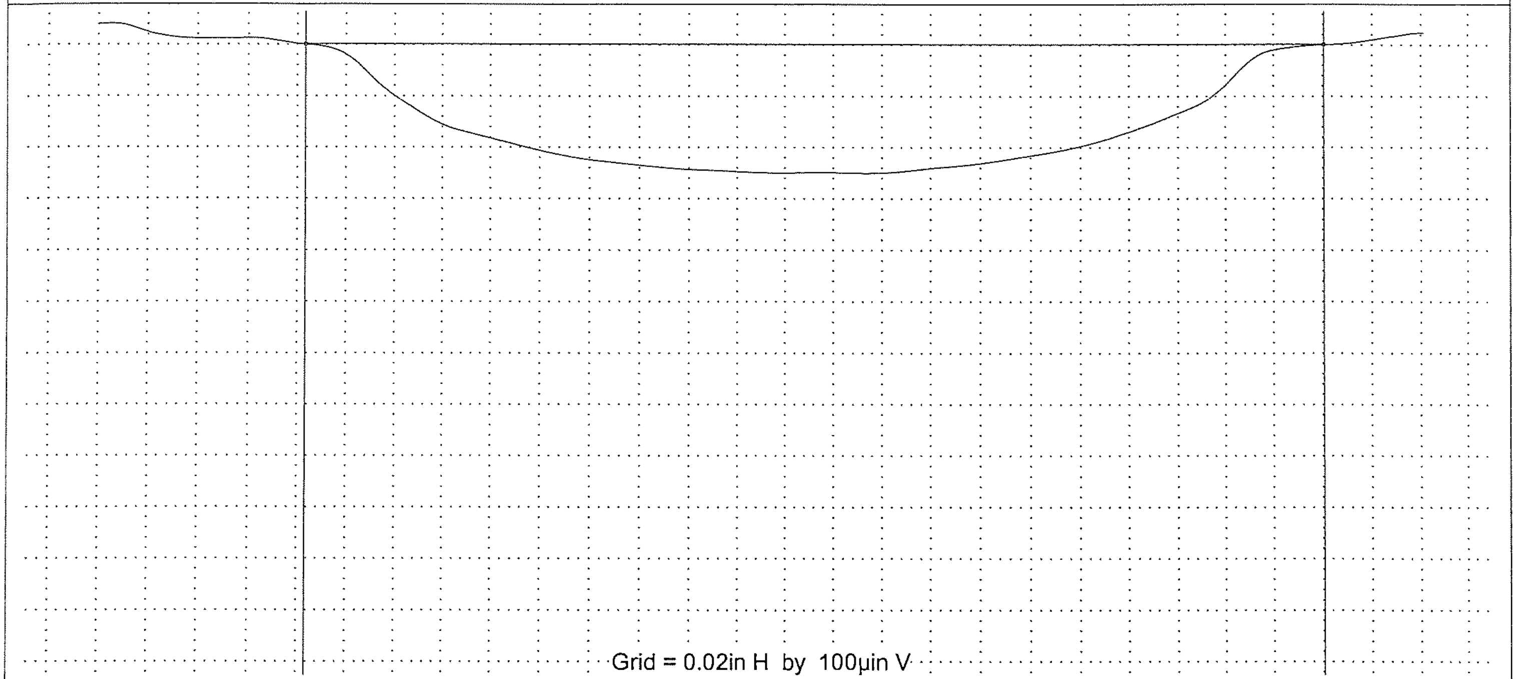
Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:35 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R4
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.I
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Description

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	189.1	µin

Profiles: Waviness



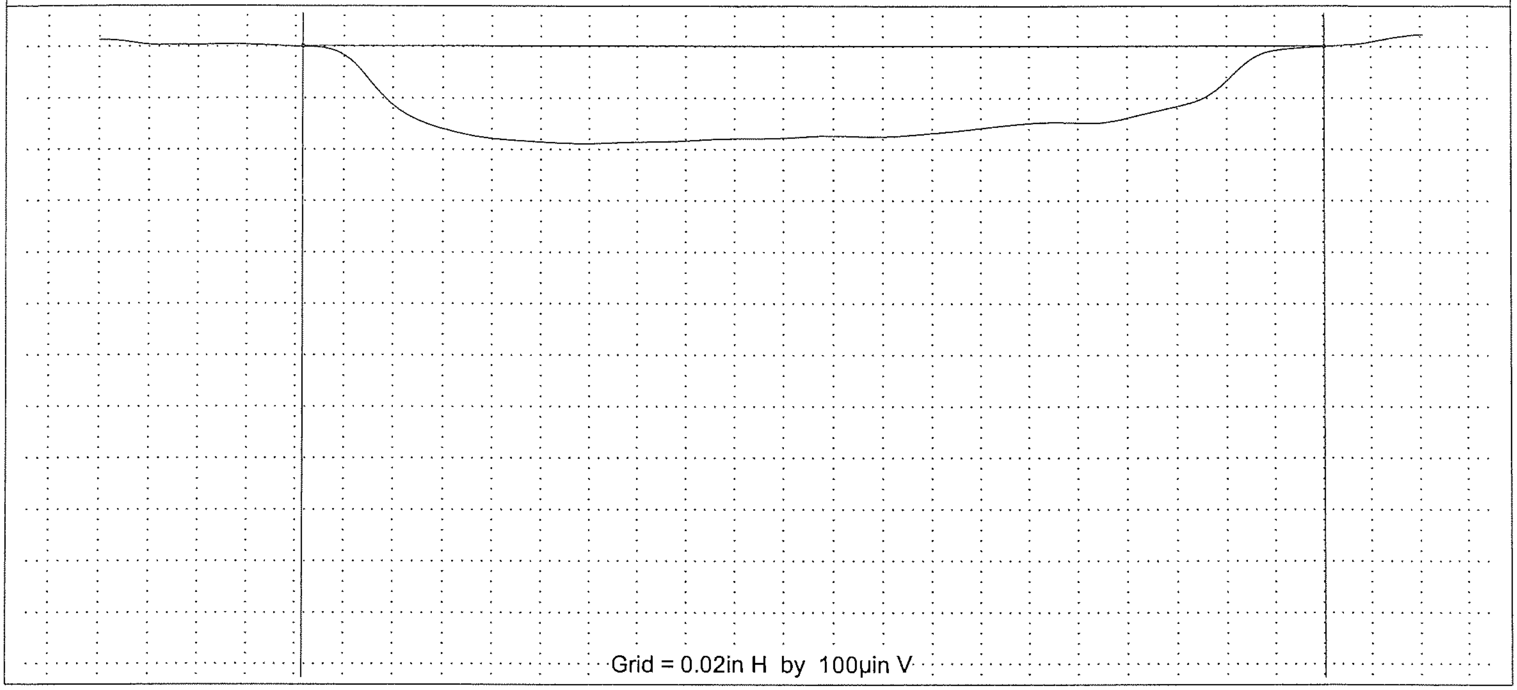
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:38 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R5
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.P
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter
  Sampled Length: 0.541 in

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	250.7	µin

Profiles: Waviness



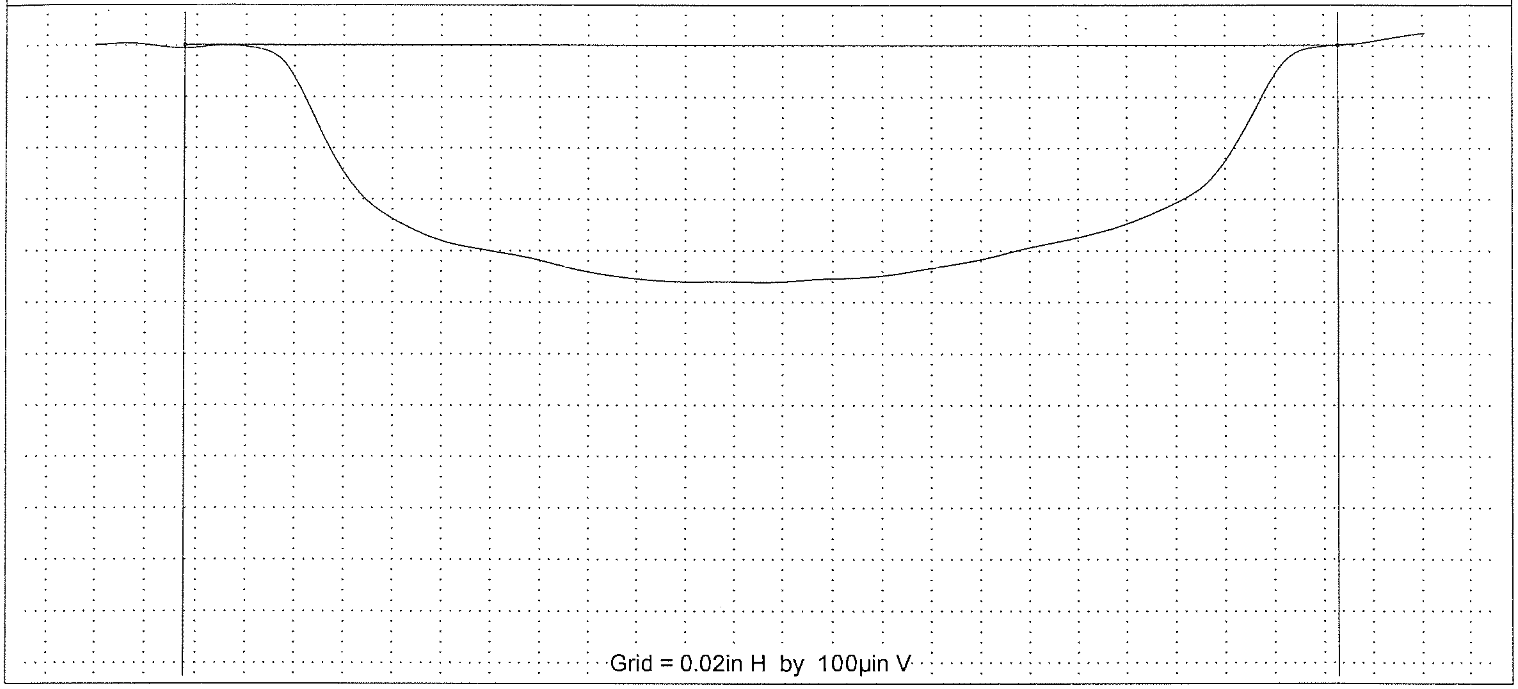
Settings

```
Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:40 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R6
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter
```

Parameters

```
  PARAMETER    VALUE     UNITS
  ---------    -----     -----
Summary
  Standards System = ANSI/ASME B46.1 1995
Waviness Parameters:
  Wt           188.8     µin
```

Profiles: Waviness

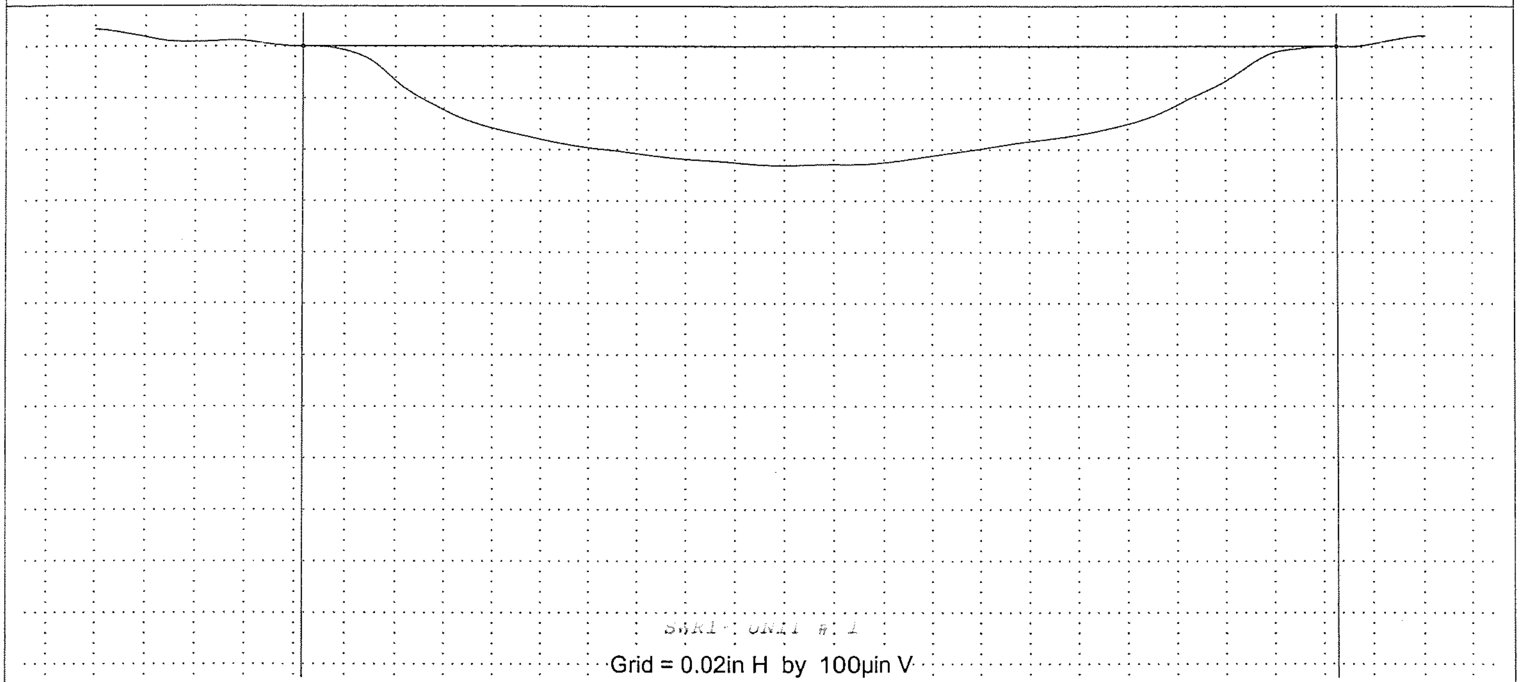


Settings
Software: 2.46; Advanced; 3.95
Data
Collected: Mon Feb 06 09:42 2012
By: Kerry McCubbin
At: SWRI- UNIT # 1
Tracer Used: PDT-2-522
Sampled Length: 0.541 in
Sample Spacing: 18.9 µin
Description
RFWT, Pin R7
Run 65-404-222-9
File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
Name: MicroAnalyzer 2000
Serial #: S-2000-3027
Current Tracer:PDT-2-522
Travel Distance: 0.541 in
Trace Velocity: 0.030 in/s
Form
Form Type: Two-Point Line
Roughness Filter
Type: Gaussian
Cutoff: 0.030 in
No Filter Width Removal at Ends
Parameter Calculation Settings
Peak Count Threshold: 19.7 µin
High Spot Count Threshold: 19.7 µin
tp Reference Percent: 5 %
tp Slice Depth: 19.7 µin
Short Wavelength Filter
Type: Gaussian
Cutoff: 0.0001 in
Waviness Filter
Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	462.2	µin

Profiles: Waviness

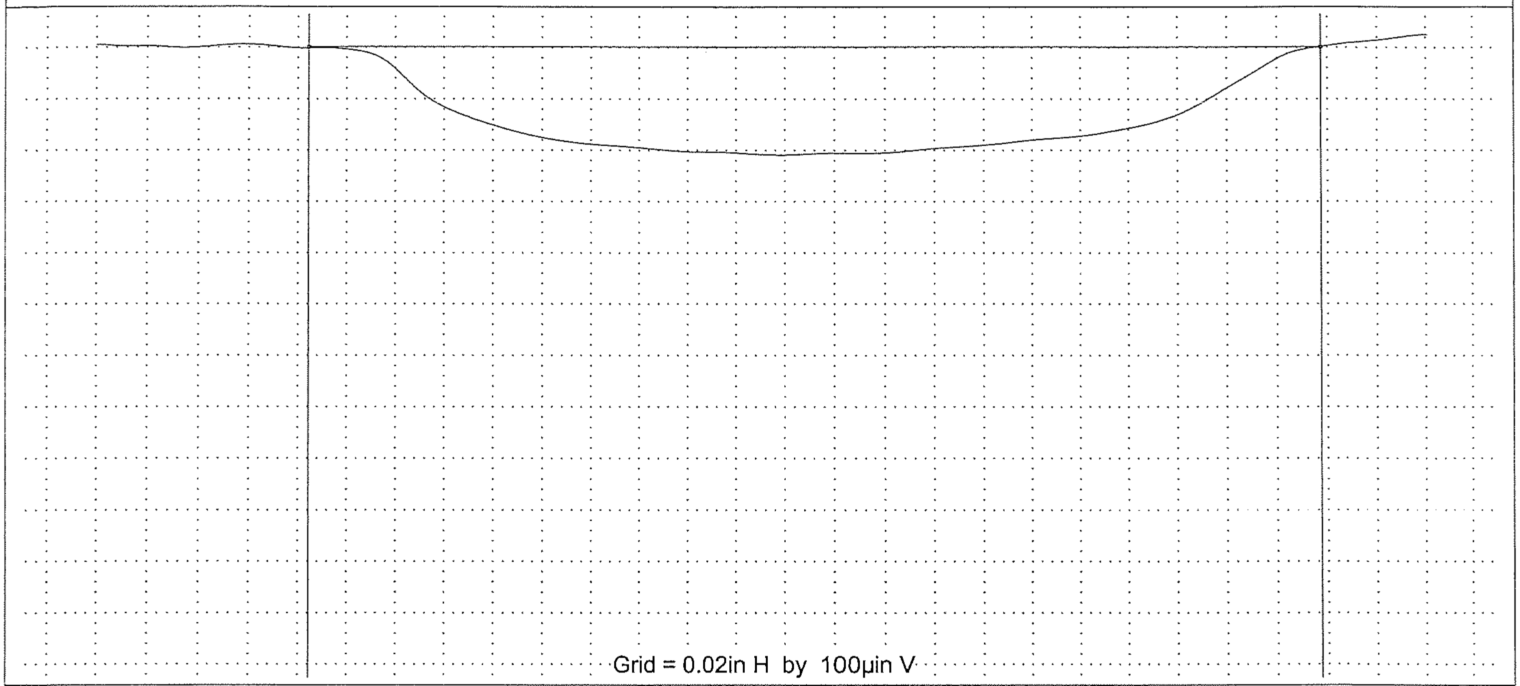


Settings
Software: 2.46; Advanced; 3.95
Data
Collected: Mon Feb 06 09:43 2012
By: Kerry McCubbin
At: SWRI- UNIT # 1
Tracer Used: PDT-2-522
Sampled Length: 0.541 in
Sample Spacing: 18.9 µin
Description
RFWT, Pin R8
Run 65-404-222-9
File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
Name: MicroAnalyzer 2000
Serial #: S-2000-3027
Current Tracer:PDT-2-522
Travel Distance: 0.541 in
Trace Velocity: 0.030 in/s
Form
Form Type: Two-Point Line
Roughness Filter
Type: Gaussian
Cutoff: 0.030 in
No Filter Width Removal at Ends
Parameter Calculation Settings
Peak Count Threshold: 19.7 µin
High Spot Count Threshold: 19.7 µin
tp Reference Percent: 5 %
tp Slice Depth: 19.7 µin
Short Wavelength Filter
Type: Gaussian
Cutoff: 0.0001 in
Waviness Filter
Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	231.6	µin

Profiles: Waviness



Grid = 0.02in H by 100µin V

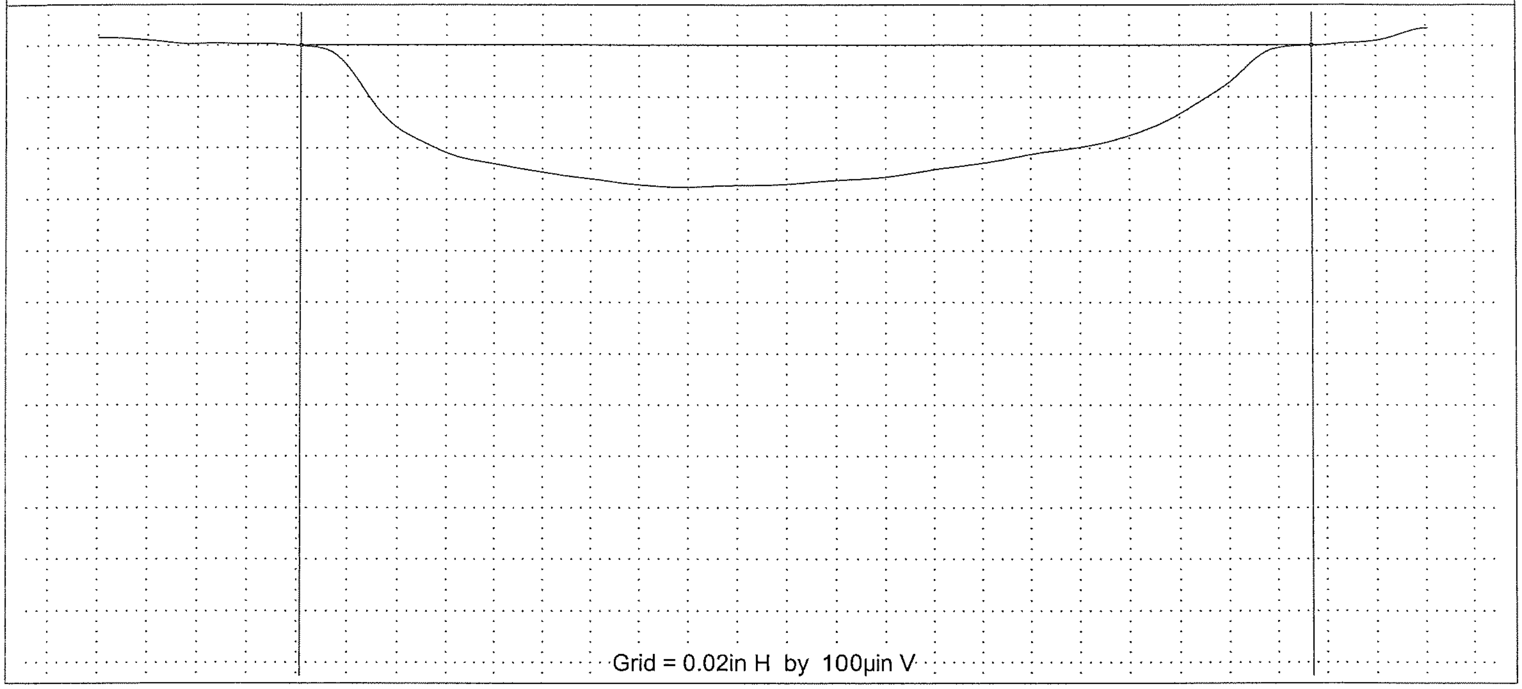
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:09 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L1
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	210.5	µin

Profiles: Waviness



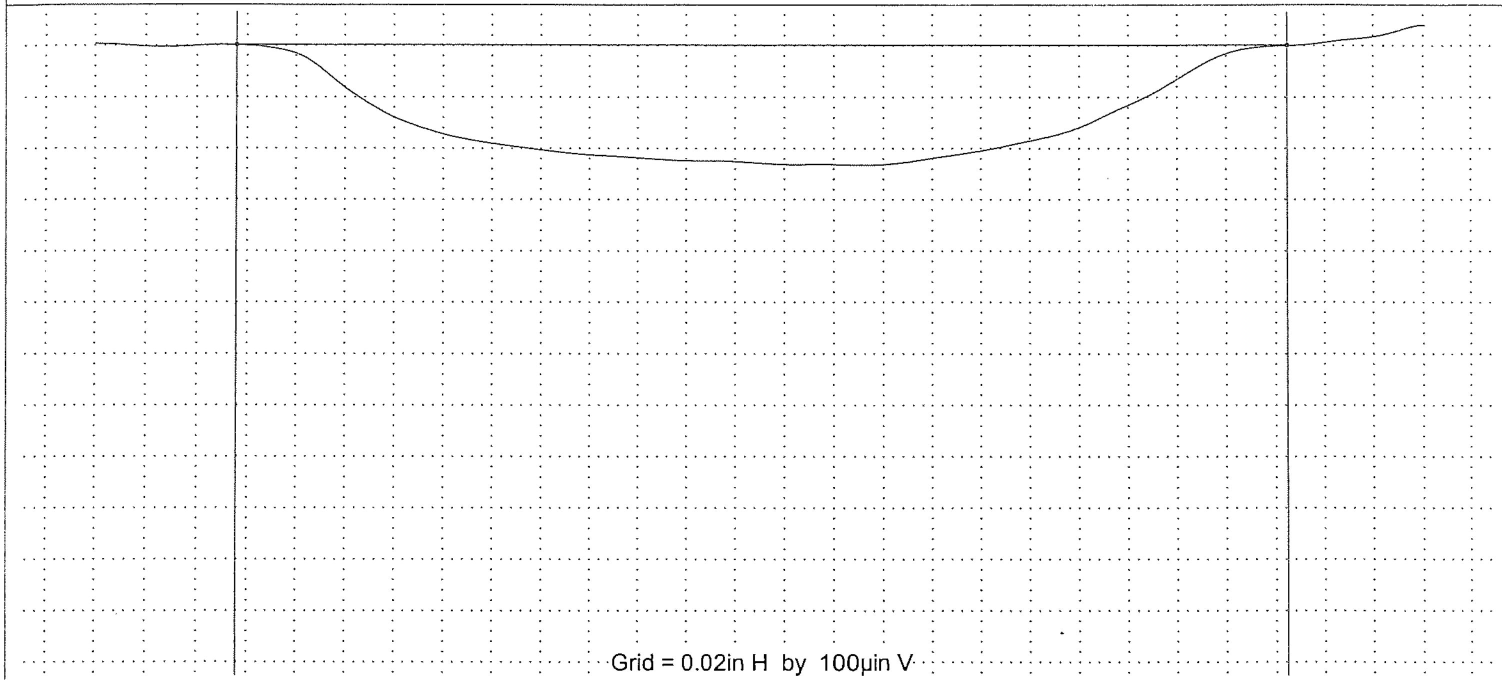
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:13 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L2
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	276.5	µin

Profiles: Waviness



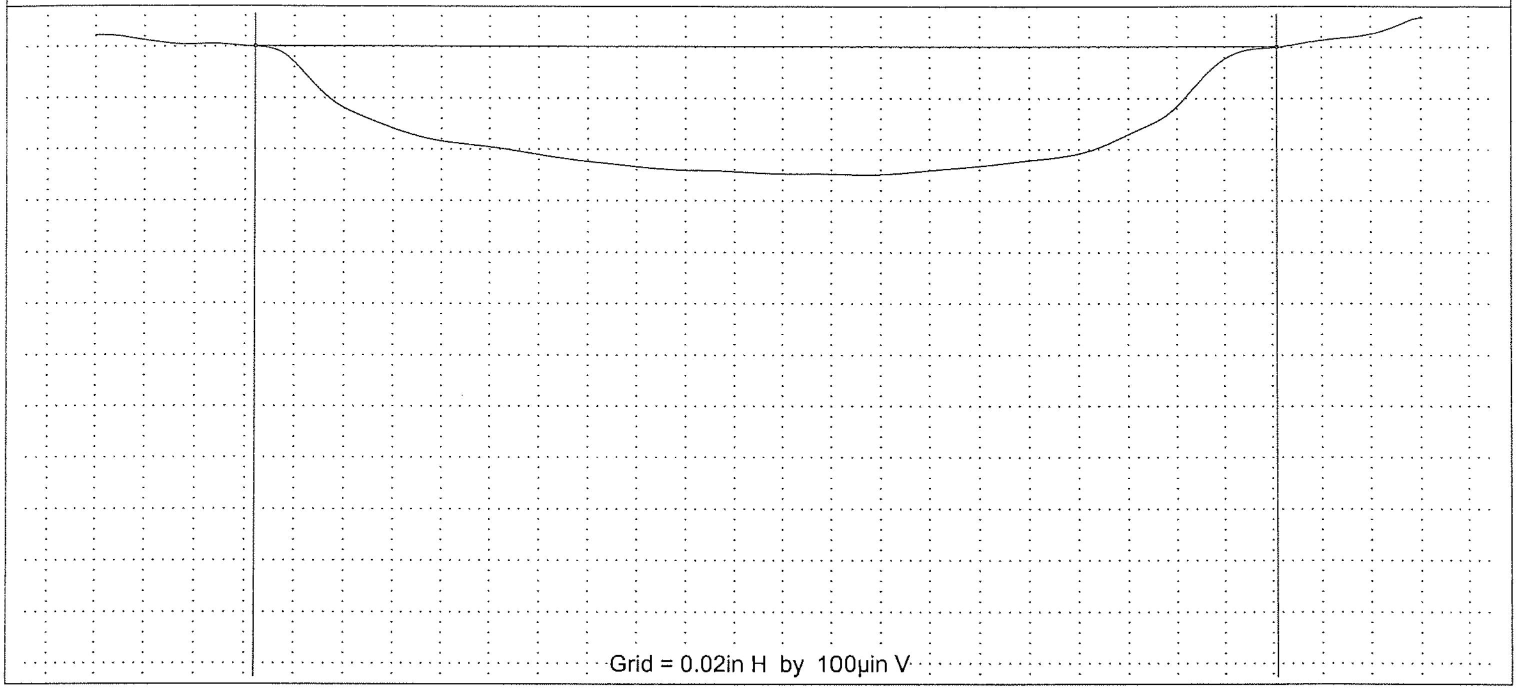
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:14 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L3
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	233.2	µin

Profiles: Waviness

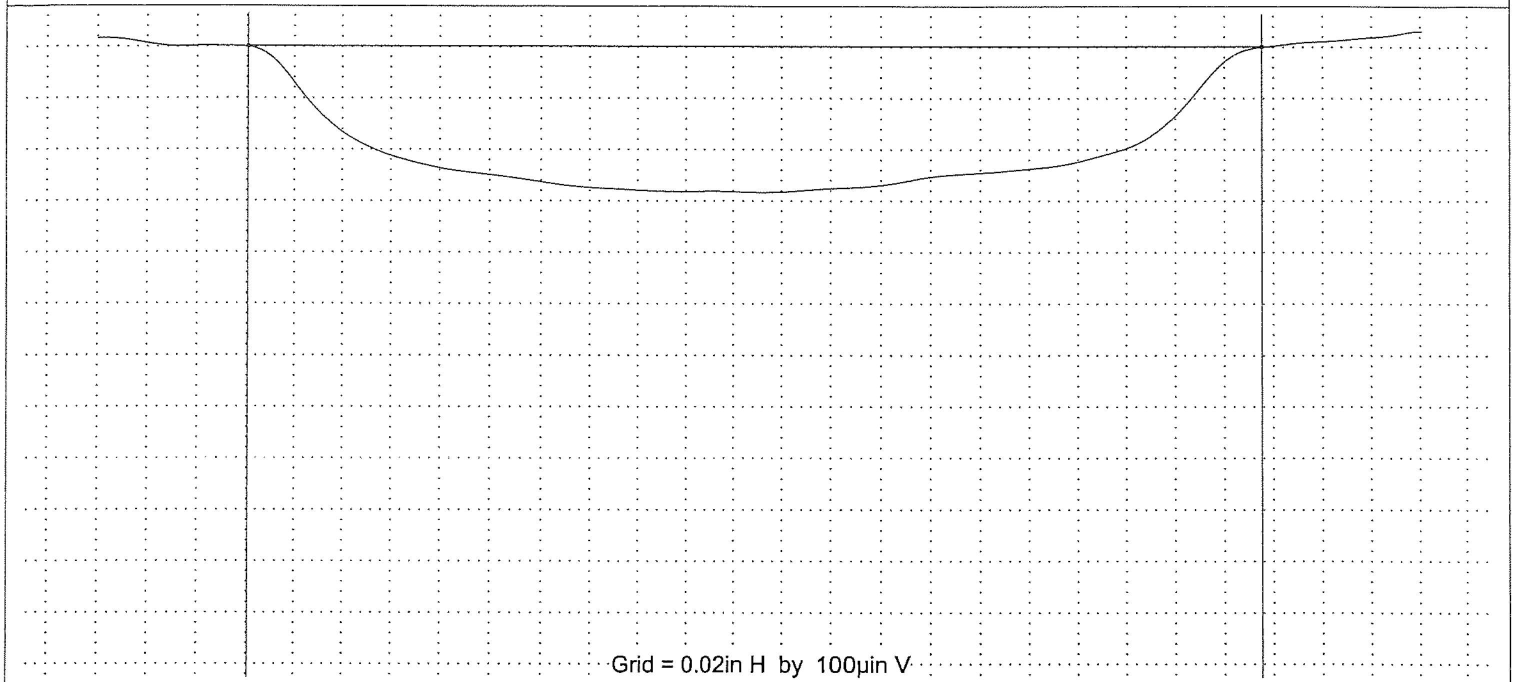


Settings
Software: 2.46; Advanced; 3.95
Data
Collected: Mon Feb 06 09:17 2012
By: Kerry McCubbin
At: SWRI- UNIT # 1
Tracer Used: PDT-2-522
Sampled Length: 0.541 in
Sample Spacing: 18.9 µin
Description
RFWT, Pin L4
Run 65-404-222-9
File: C:\S-2000-2\DATA\RFWT\40422209.F
Instrument
Name: MicroAnalyzer 2000
Serial #: S-2000-3027
Current Tracer:PDT-2-522
Travel Distance: 0.541 in
Trace Velocity: 0.030 in/s
Form
Form Type: Two-Point Line
Roughness Filter
Type: Gaussian
Cutoff: 0.030 in
No Filter Width Removal at Ends
Parameter Calculation Settings
Peak Count Threshold: 19.7 µin
High Spot Count Threshold: 19.7 µin
tp Reference Percent: 5 %
tp Slice Depth: 19.7 µin
Short Wavelength Filter
Type: Gaussian
Cutoff: 0.0001 in
Waviness Filter
Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	249.4	µin

Profiles: Waviness



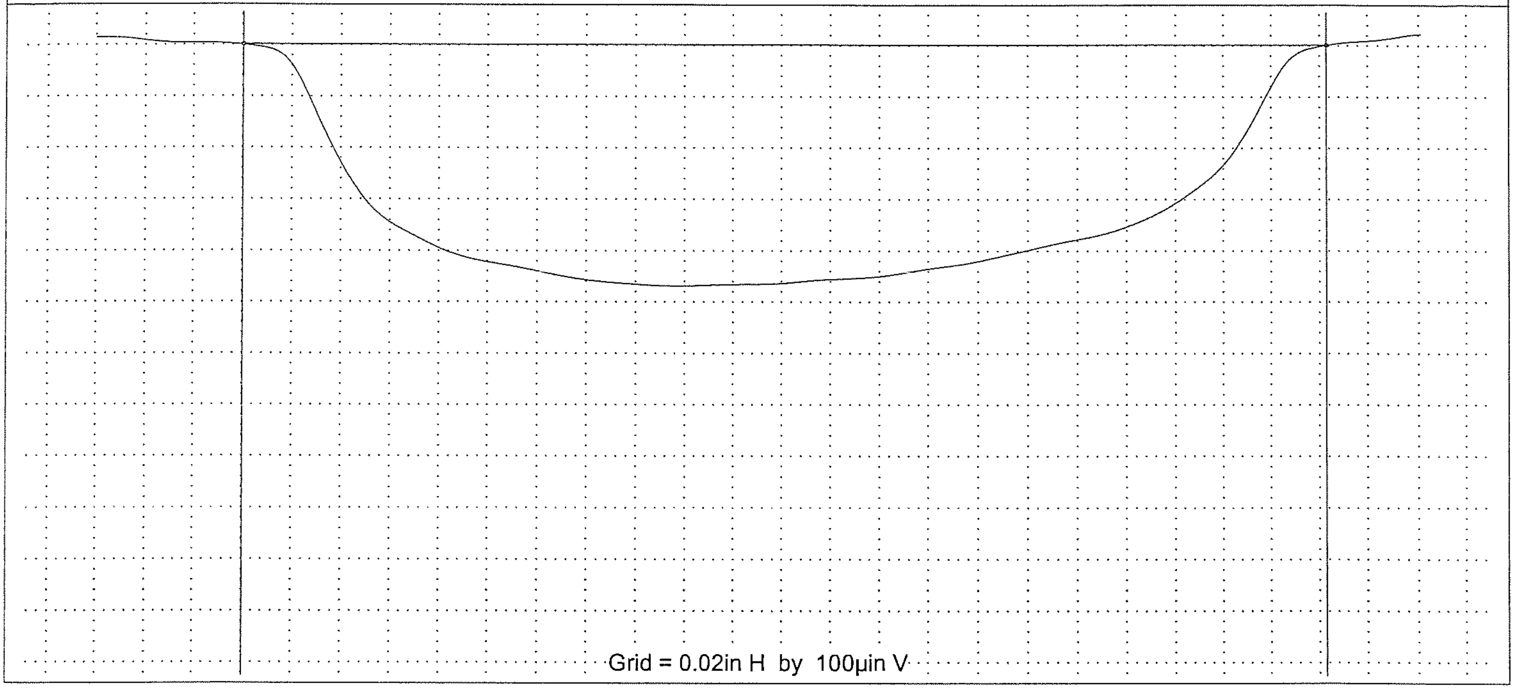
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:20 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L5
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	283.2	µin

Profiles: Waviness



Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:22 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L6
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.P
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

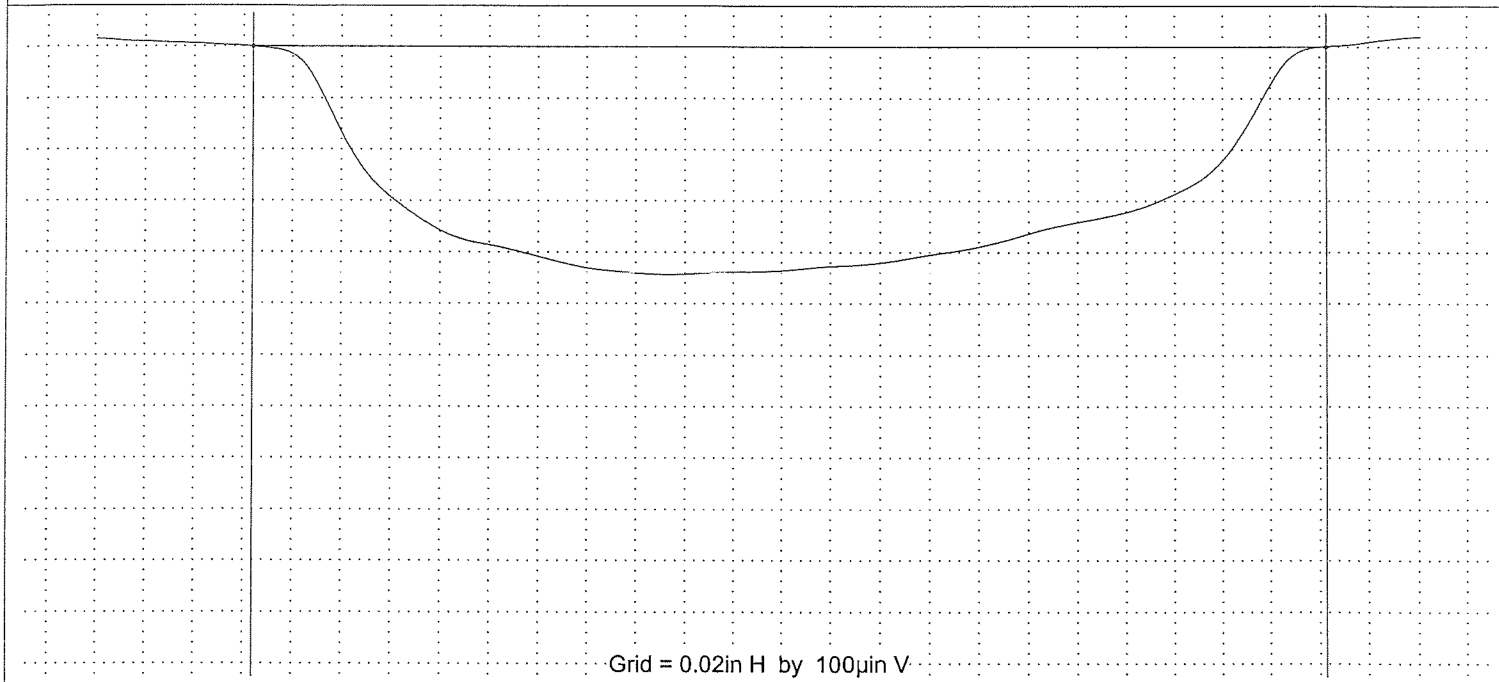
RFWT, Pin L6

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	469.5	µin

Parameters

Profiles: Waviness



Settings

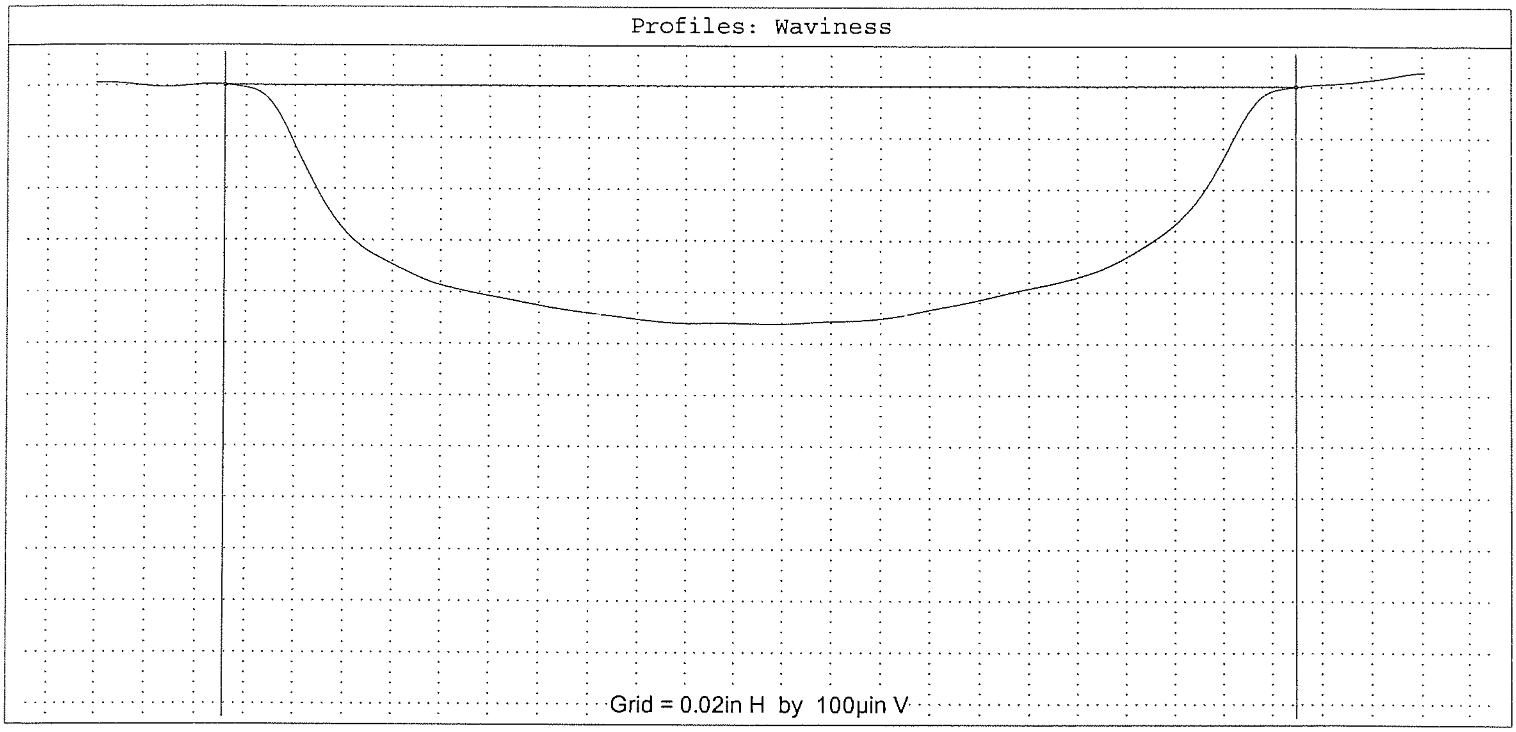
Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:24 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 μin
Description
  RFWT, Pin L7
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 μin
  High Spot Count Threshold: 19.7 μin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 μin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Sample Spacing: 18.9 μin

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	444.5	μin

Profiles: Waviness



Settings

Software: 2.46; Advanced; 3.95
Data
Collected: Mon Feb 06 09:26 2012
By: Kerry McCubbin
At: SWRI- UNIT # 1
Tracer Used: PDT-2-522
Sampled Length: 0.541 in
Sample Spacing: 18.9 µin
Description
RFWT, Pin L8
Run 65-404-222-9
File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
Name: MicroAnalyzer 2000
Serial #: S-2000-3027
Current Tracer:PDT-2-522
Travel Distance: 0.541 in
Trace Velocity: 0.030 in/s
Form
Form Type: Two-Point Line
Roughness Filter
Type: Gaussian
Cutoff: 0.030 in
No Filter Width Removal at Ends
Parameter Calculation Settings
Peak Count Threshold: 19.7 µin
High Spot Count Threshold: 19.7 µin
tp Reference Percent: 5 %
tp Slice Depth: 19.7 µin
Short Wavelength Filter
Type: Gaussian
Cutoff: 0.0001 in
Waviness Filter
Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	463.4	µin

Laboratory: SR	**EOT Date:** 20120203
Test Number: * 65-404-222-9	
Oil Code: LO-268869	
Formulation / Stand Code:	

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Appendix B

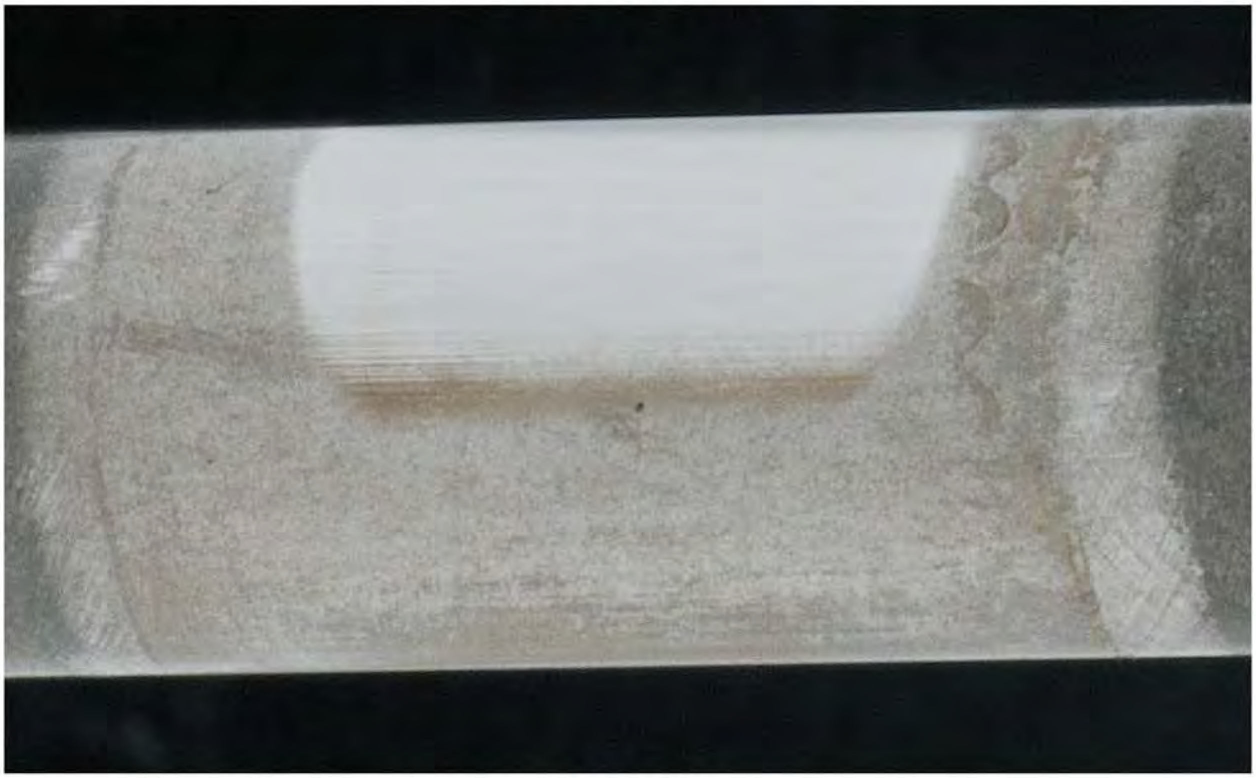
Roller Follower Wear Test Photographs

1. Roller Follower Axle Pin Wear Best
2. Roller Follower Axle Pin Wear Worst

Roller Follower Wear Test

Laboratory:	SR	**Oil Code:**	LO-268869
Test Stand No.:	65	**Test No.:**	65-404-222-9
Laboratory Oil Code:	268869	**Test Hours:**	50
Formulation / Stand Code:			

Roller Axle Wear

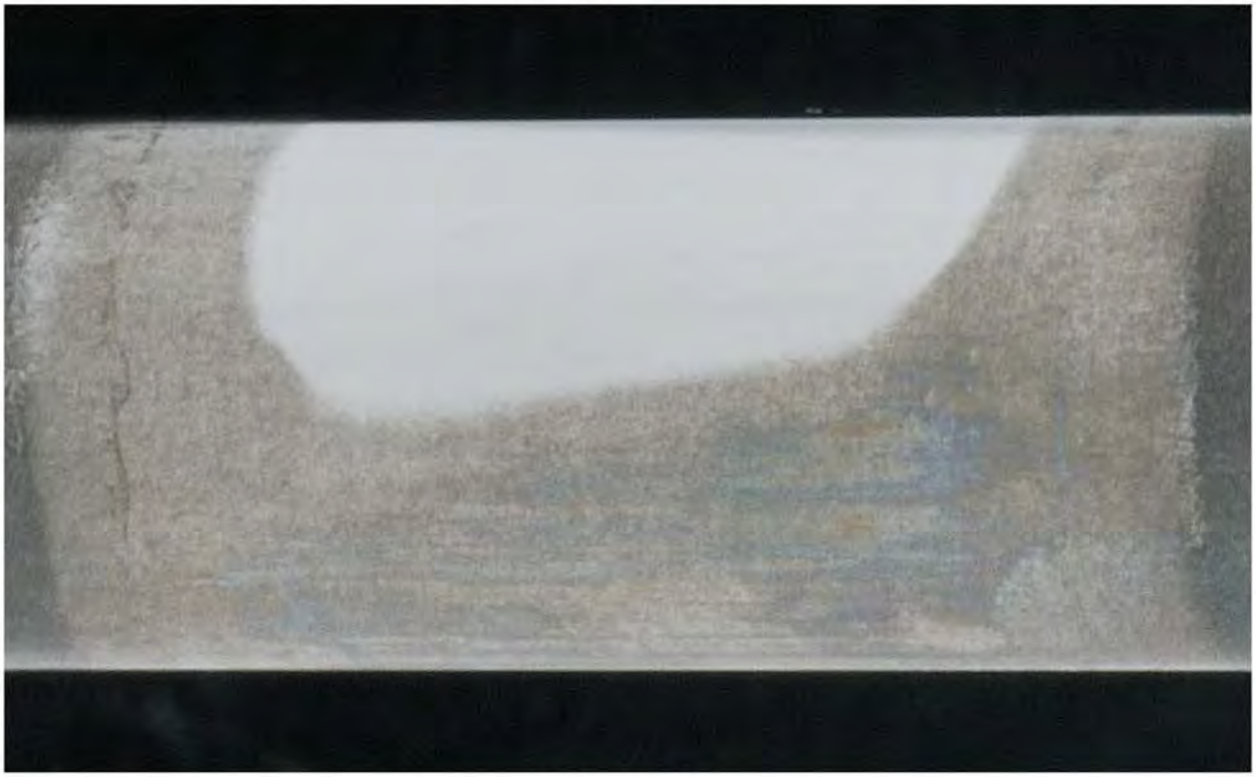


Best 3R

Roller Follower Wear Test

Laboratory:	SR	**Oil Code:**	LO-268869
Test Stand No.:	65	**Test No.:**	65-404-222-9
Laboratory Oil Code:	268869	**Test Hours:**	50
Formulation / Stand Code:			

Roller Axle Wear



Worst 6L

APPENDIX – C2
ROLLER FOLLOWER WEAR TEST
LO-271510

D 5966
Roller Follower Wear Test

Version 20040401

Title / Validity Declaration Page

Conducted for

US ARMY TARDEC

V	V =	Valid; The Reference Oil / Non-Reference Oil was Evaluated in Accordance with the Test Prodecure.
	I =	Invalid; The Reference Oil / Non-Reference Oil was Evaluated in Accordance with the Test Procedure.

Stand: 65	**Stand Run No.:** 405	**Engine No.:** 222	**Engine Run No.:** 10
End of Test Date: 20120206		**End of Test Time:** 05:23 CST	
Oil Code:* LO-271510			
Formulation / Stand Code:[A]			
Alternate Codes:[B]			

In my opinion this test has been conducted in a valid manner in accordance with the Test Method D 5966 and the appropriate amendments through the information letter system. The remarks included in the report describe the anomalies associated with this test.

The results of this report relate only to the items tested.

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** CMIR or Non-Reference Oil Code*

[A] *ACC -Registered Tests Only*

[B] *When Provided or Required by Client*

Submitted by:

Southwest Research Institute (R)

Testing Laboratory

Signature

Perry Grosch

Typed Name

Principal Research Technologist

Title

D 5966
Roller Follower Wear Test
Test Identification Cover Sheet
Test Lab Affidavit
Form 1

Reference Oil Test

Lab	Stand	Stand Run No.	Engine	Engine Run No.
SR	65		222	

Start Date	Date Completed	EOT of Test Time	Test Length
			0

CMIR	TMC Oil Code	Viscosity Grade

Laboratory Oil Code	
Engine Displacement	6.5L

[redacted]

Average Wear (mils)	
	[redacted]

Non-Reference Oil Test

Lab	Stand	Stand Run No.	Engine	Engine Run No.
SR	65	405	222	10

Start Date	Date Completed	EOT of Test Time	Test Length
20120204	20120206	05:23	50

Oil Code	Viscosity Grade
LO-271510	N/A

Laboratory Oil Code	271510

Formulation / Stand Code

Average Wear (mils)	Severity Adjustment	Adjustment Average Wear
0.15	0.00	0.15

C2 - 3

D 5966
Roller Follower Wear Test
Summary of Roller Follower Wear
Form 2

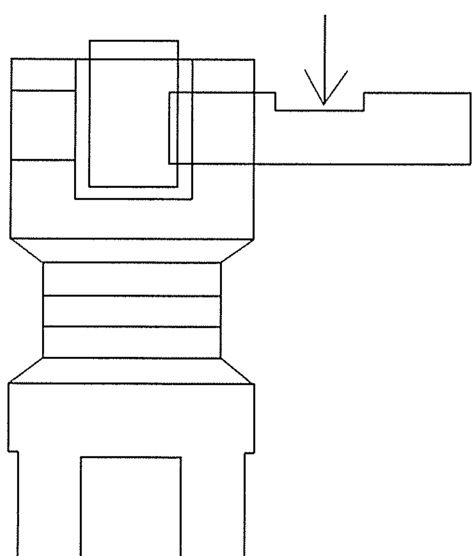
Laboratory:	SR	**EOT Date:**	20120206
Test Number: *	65-405-222-10		
Oil Code:	LO-271510		
Formulation / Stand Code:			

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Lifter Part Number
17109650

Profilometer Wear Measurements (mils)			
Lifter Number	**Wear (mils)**	**Lifter Number**	**Wear (mils)**
1L	0.12	1R	0.07
2L	0.20	2R	0.13
3L	0.31	3R	0.15
4L	0.17	4R	0.12
5L	0.18	5R	0.19
6L	0.11	6R	0.08
7L	0.11	7R	0.13
8L	0.22	8R	0.12
Wear Statistics			
Minimum	**Maximum**	**Average**	**Std. Deviation**
0.07	0.31	0.15	0.06

Wear is Measured at Location Shown by Arrow.



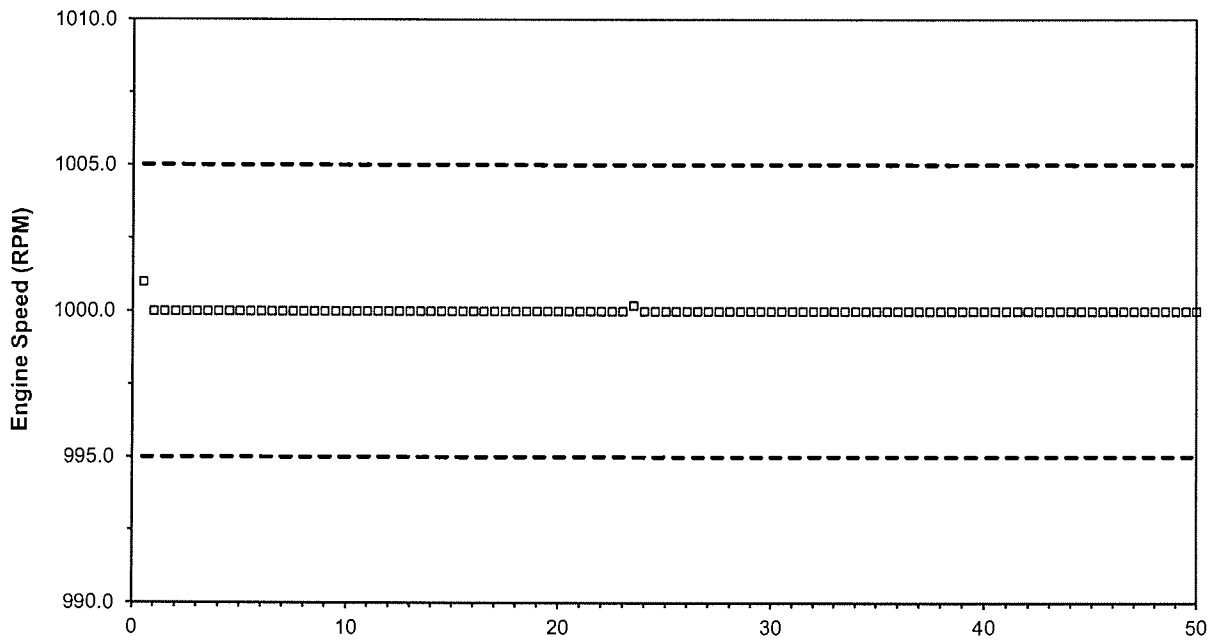
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 3

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

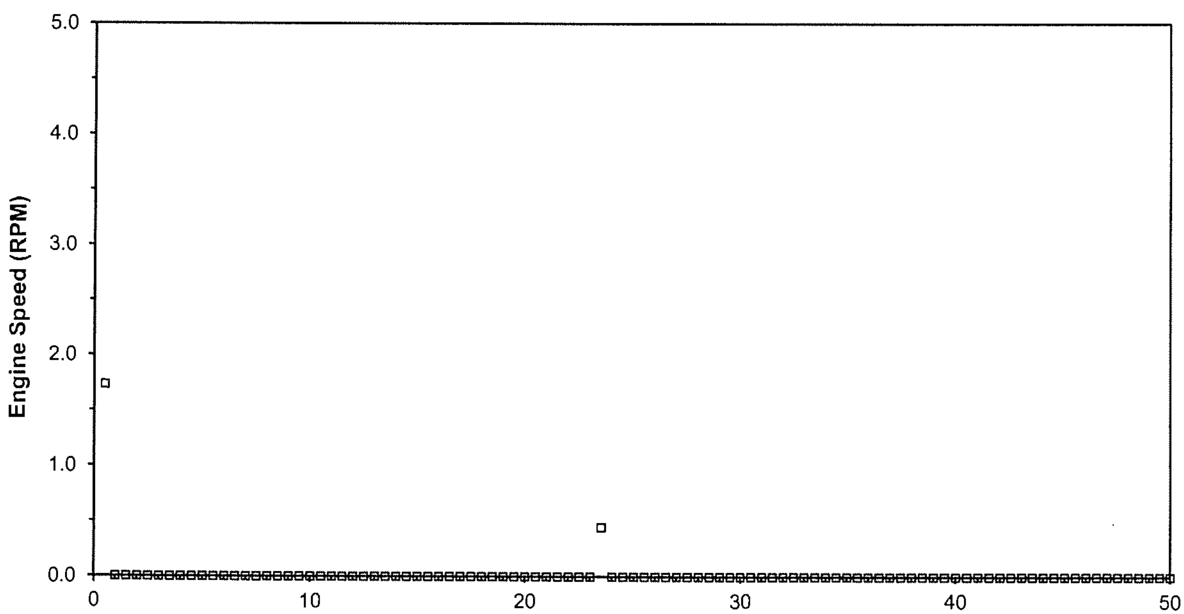
Test Number Is: Stand - Stand Run No. - Engine No.

ENGINE SPEED vs TEST HOURS

Process Mean
Xav = 1000.0



Process Variability (s)
Sav = 0.0



C2 - 5

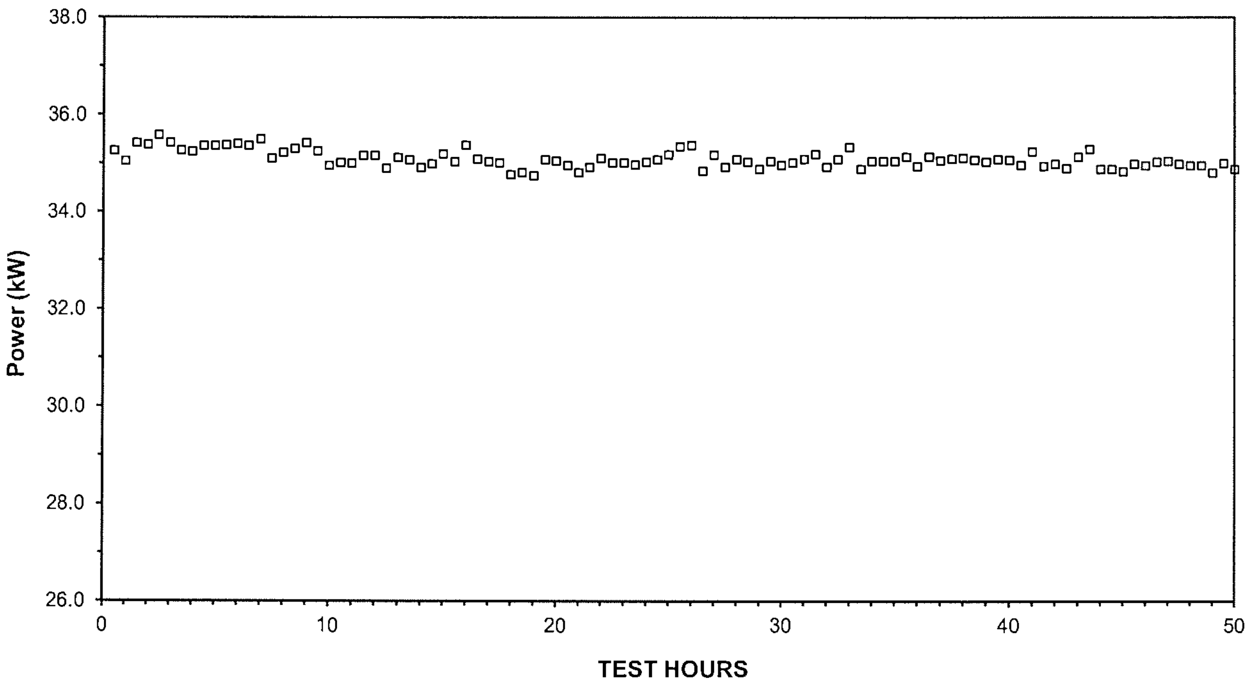
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 4

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

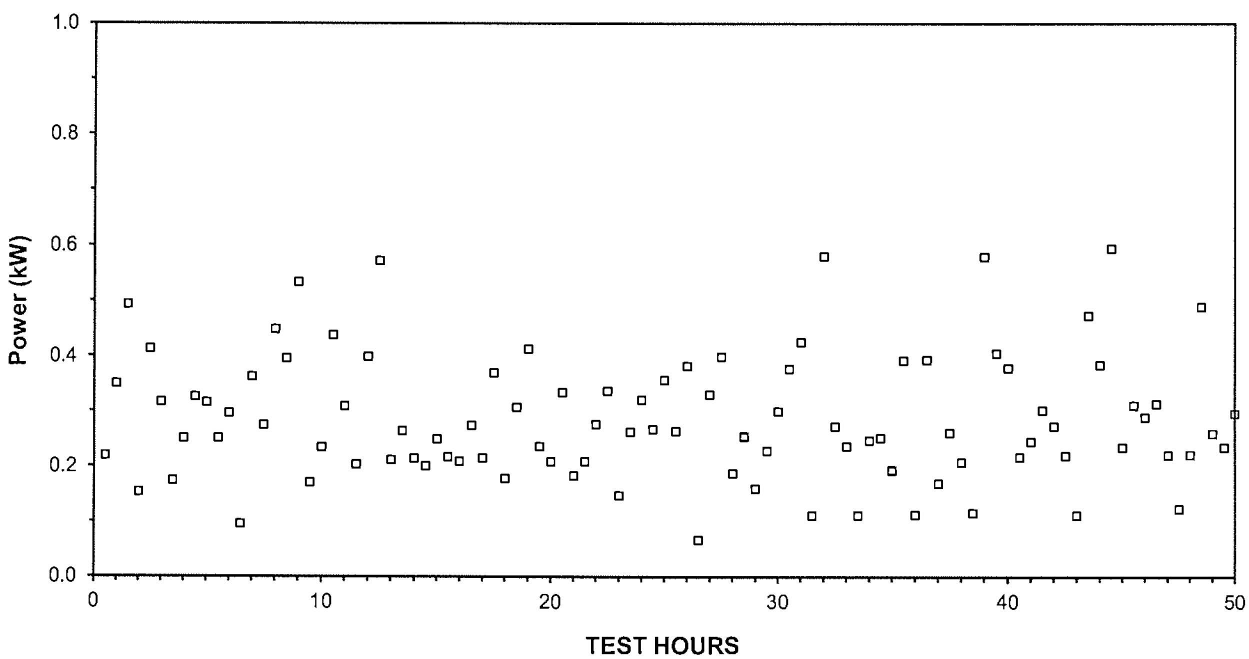
Test Number Is: Stand - Stand Run No. - Engine No.

POWER vs TEST HOURS

Process Mean
Xav = 35.1



Process Variability (s)
Sav = 0.3



C2 - 6

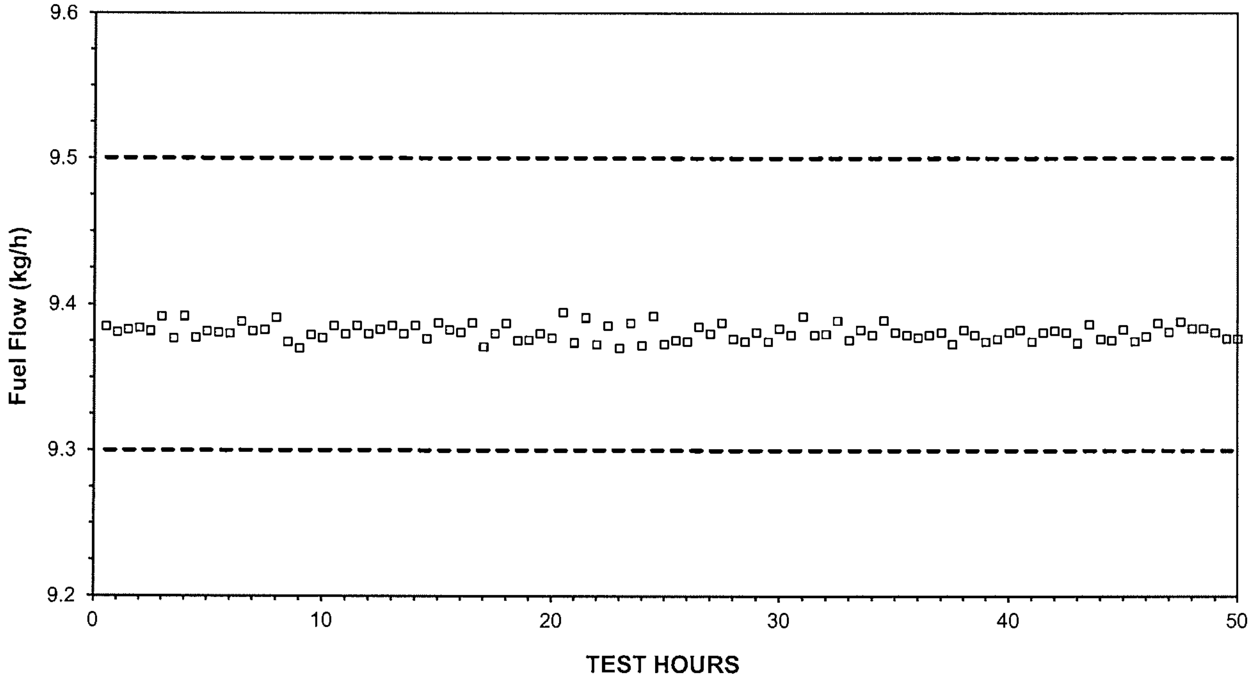
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 5

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

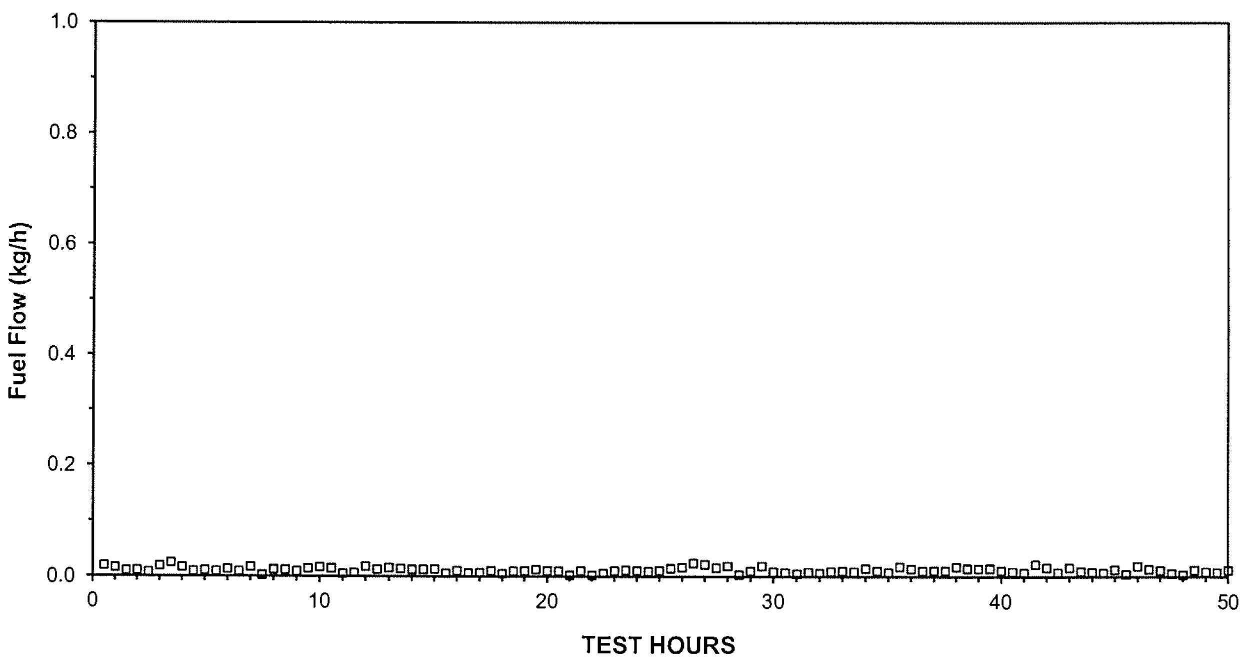
***Test Number Is: Stand - Stand Run No. - Engine No.**

FUEL FLOW vs TEST HOURS

Process Mean
Xav = 9.4



Process Variability (s)
Sav = 0.0



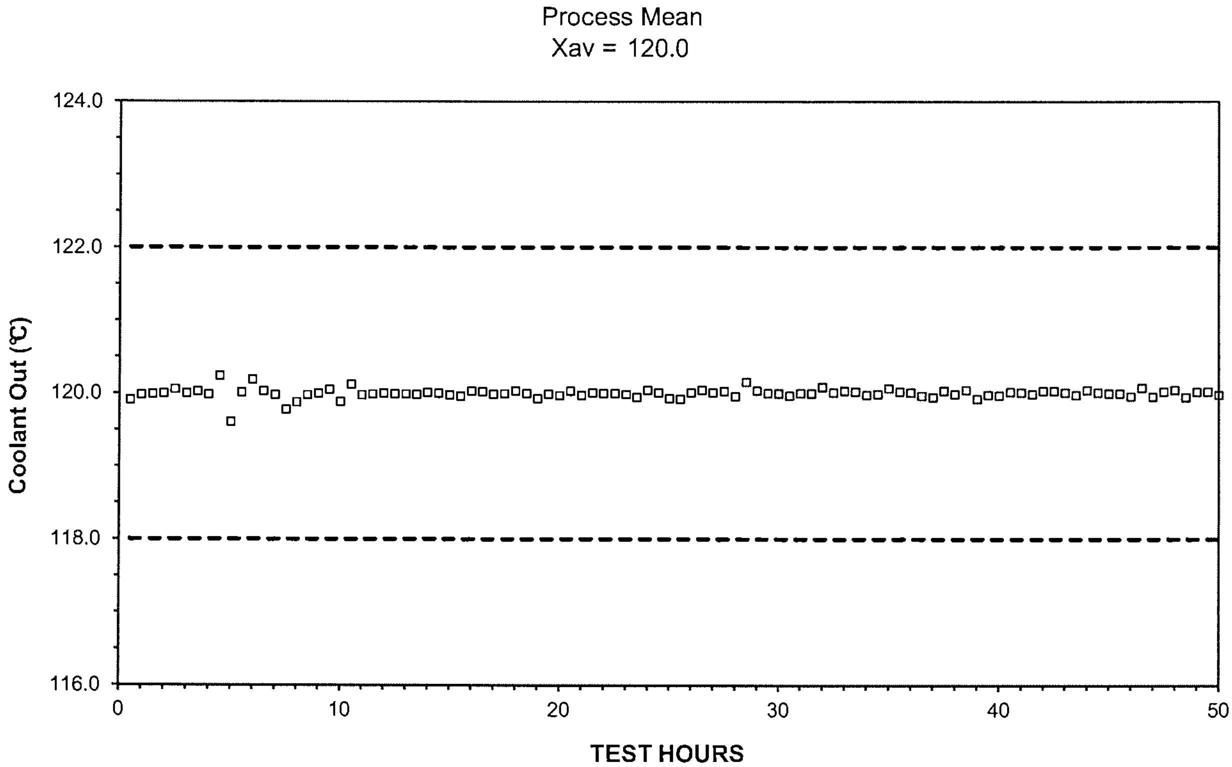
C2 - 7

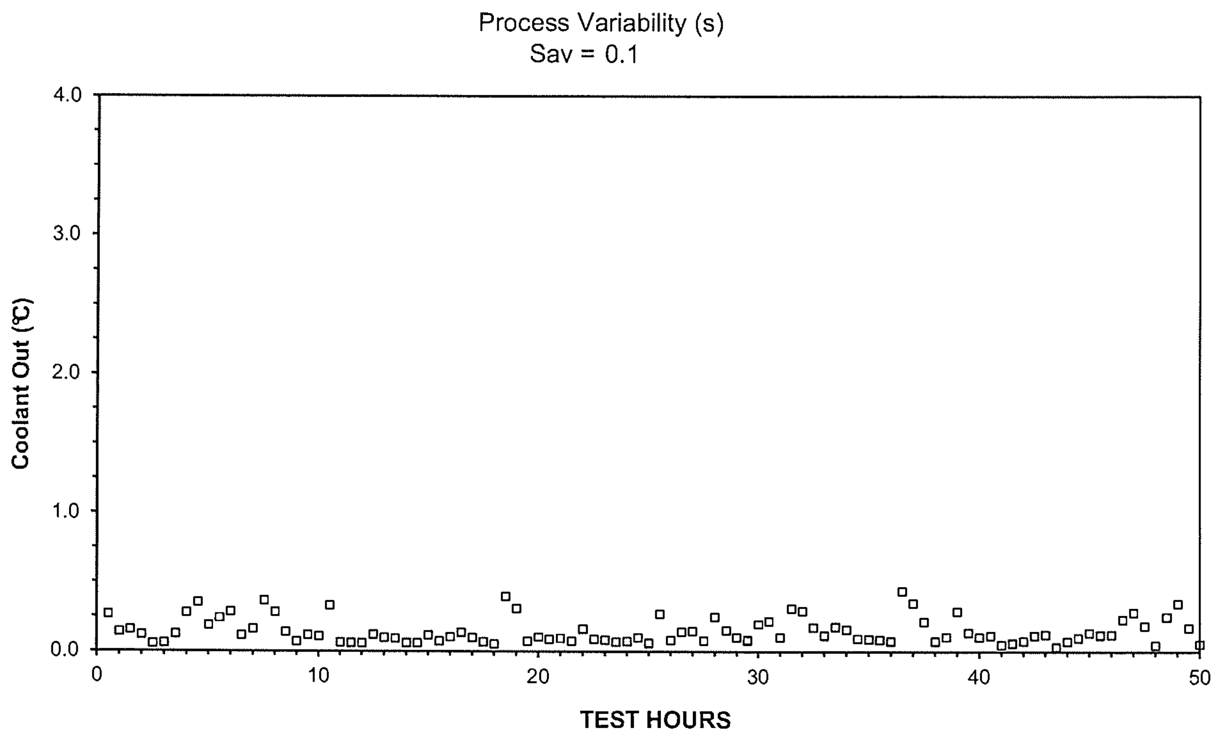
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 6

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

***Test Number Is: Stand - Stand Run No. - Engine No.**

COOLANT OUT TEMPERATURE vs TEST HOURS





C2 - 8

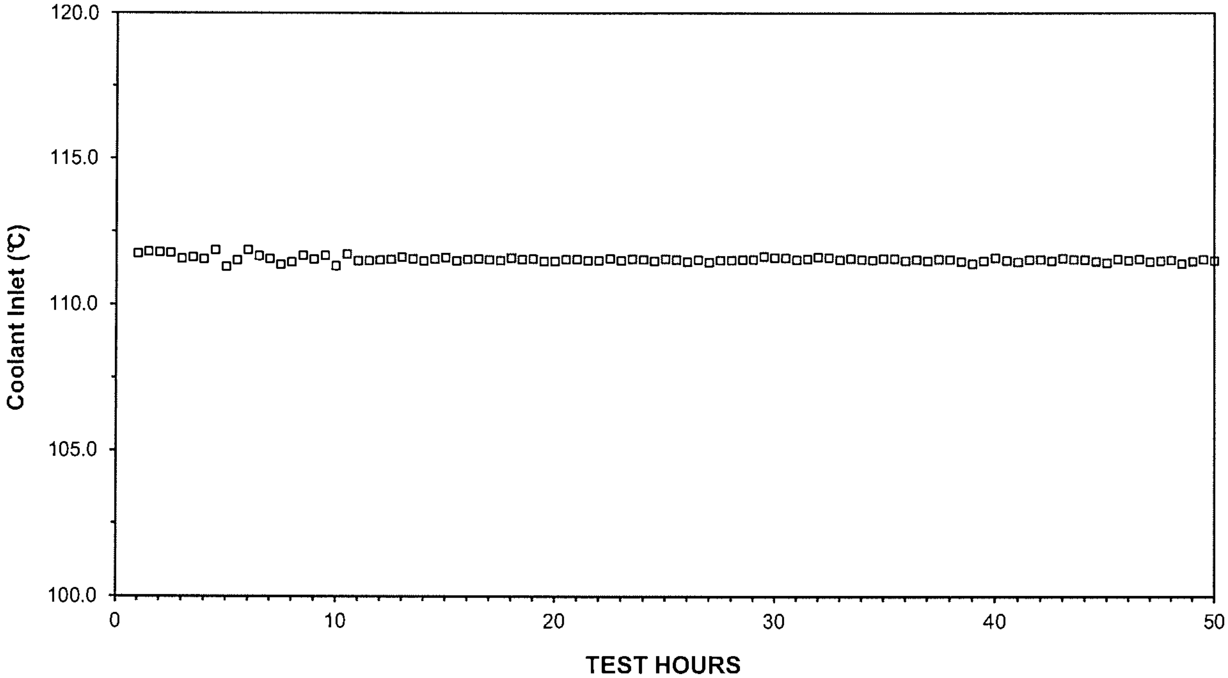
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 7

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

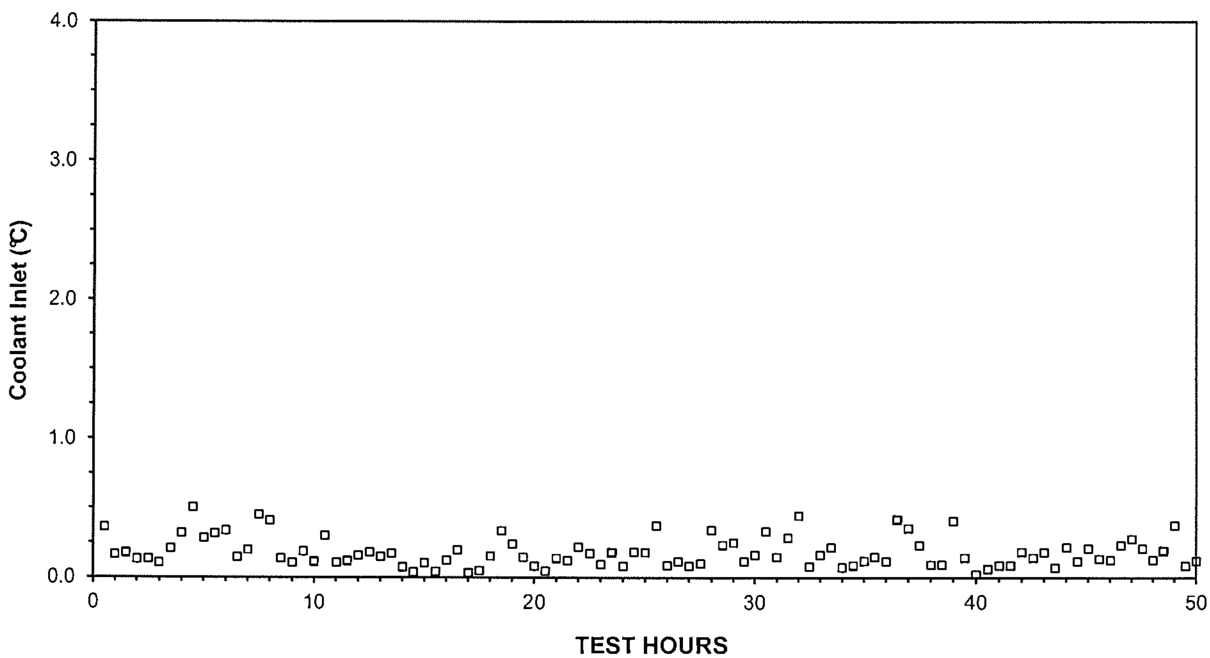
Test Number Is: Stand - Stand Run No. - Engine No.

COOLANT INLET TEMPERATURE vs TEST HOURS

Process Mean
Xav = 111.6



Process Variability (s)
Sav = 0.2



C2 - 9

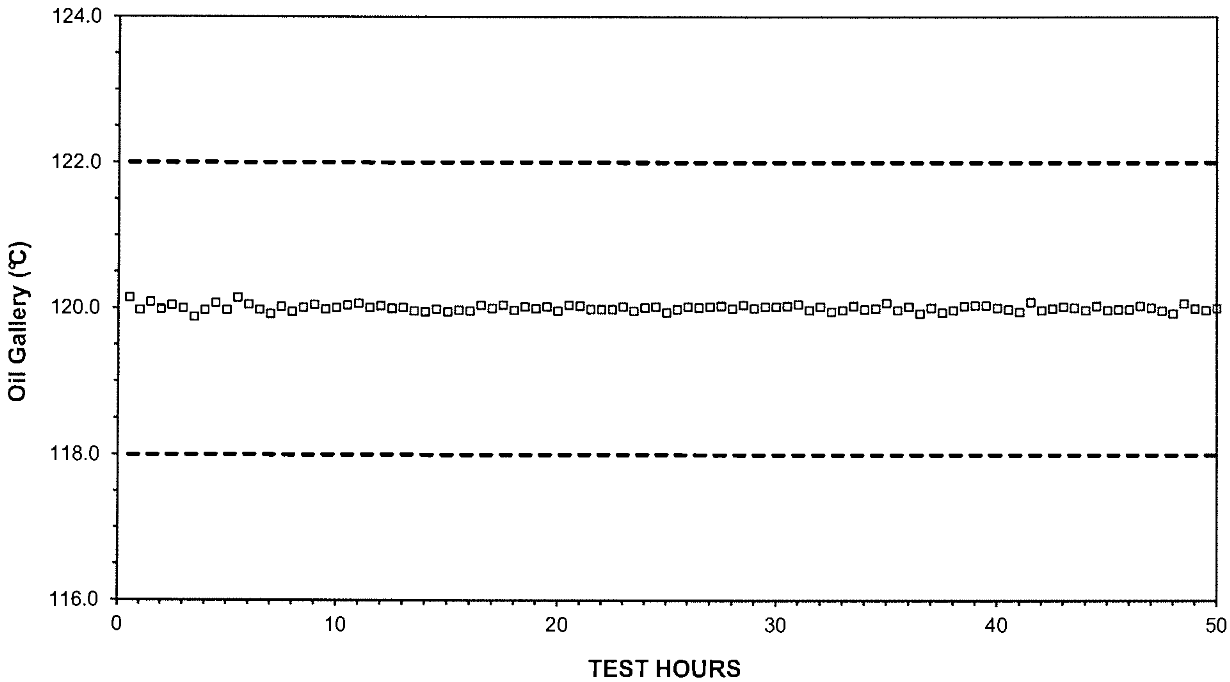
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 8

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

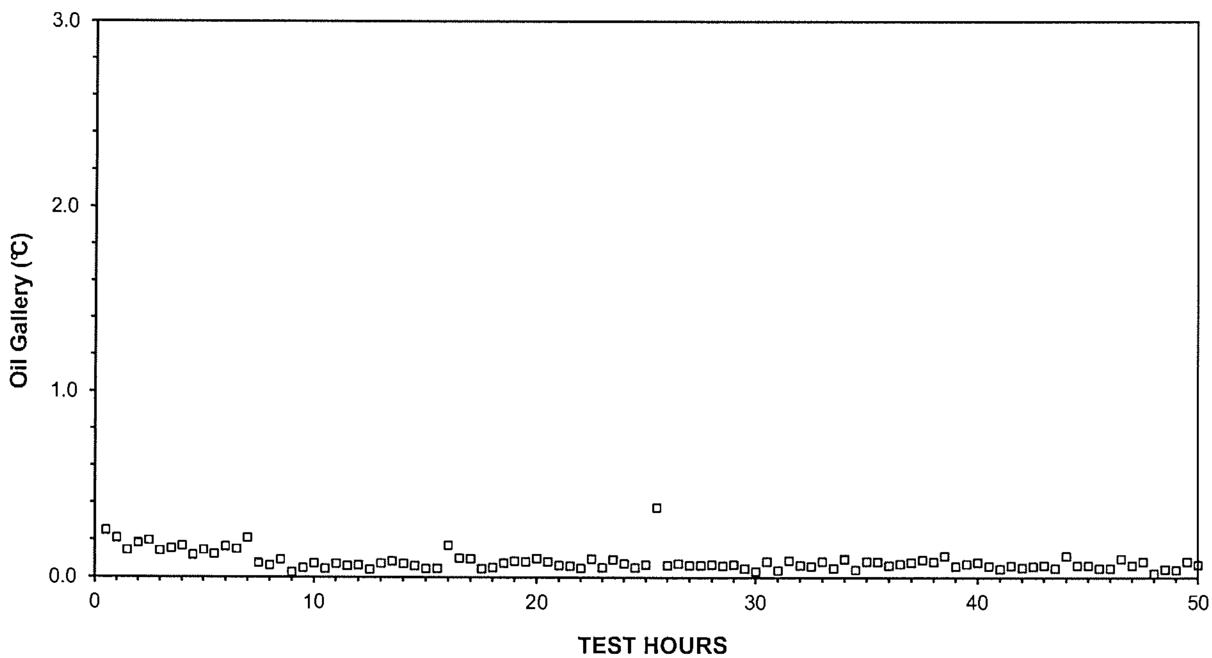
Test Number Is: Stand - Stand Run No. - Engine No.

OIL GALLERY TEMPERATURE vs TEST HOURS

Process Mean
Xav = 120.0



Process Variability (s)
Sav = 0.1



C2 - 10

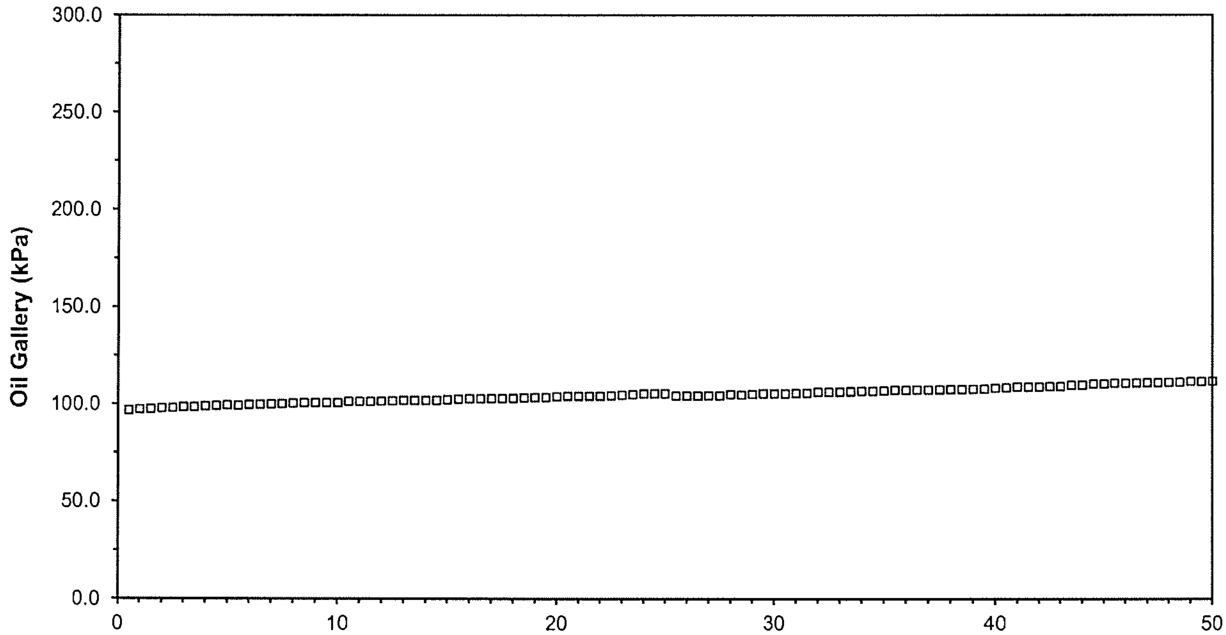
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 9

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

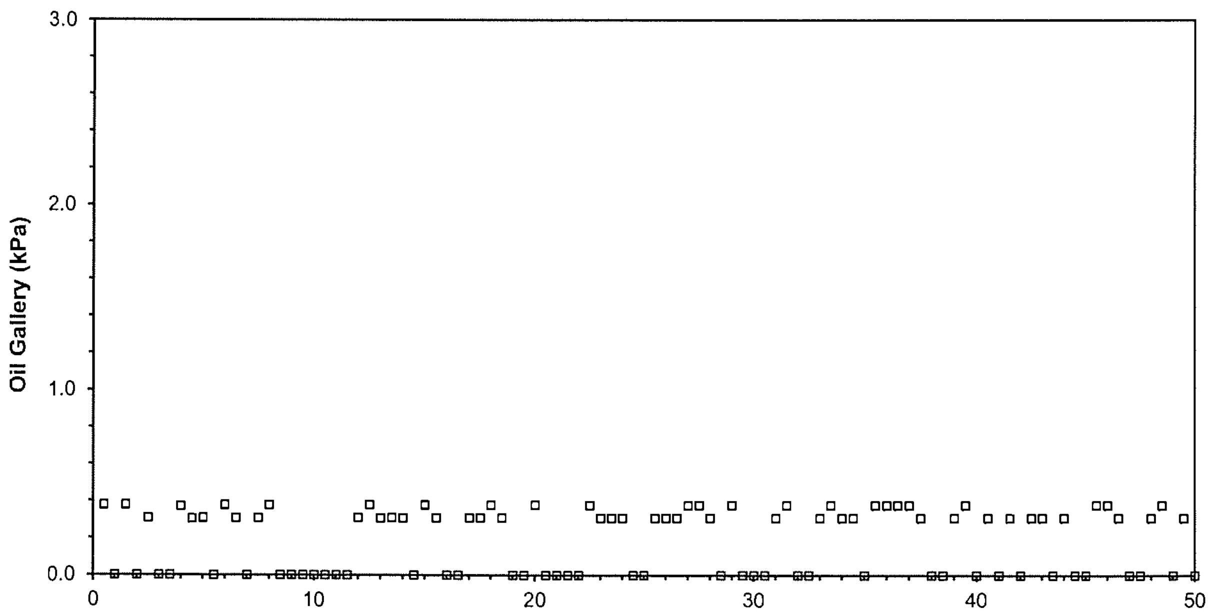
Test Number Is: Stand - Stand Run No. - Engine No.

OIL GALLERY PRESSURE vs TEST HOURS

Process Mean
Xav = 104.7



Process Variability (s)
Sav = 0.2



C2 - 11

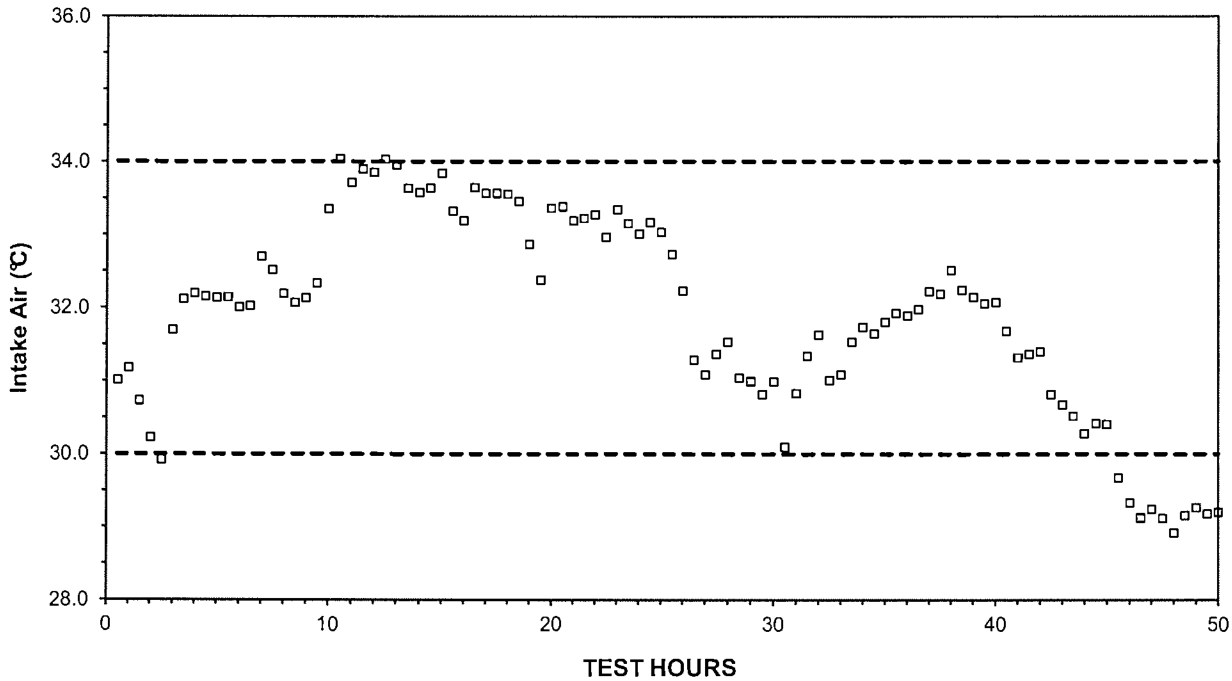
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 10

Laboratory:	SR	EOT Date:	20120206
Test Number:	65-405-222-10		
Oil Code:	LO-271510		
Formulation/Stand Code:			

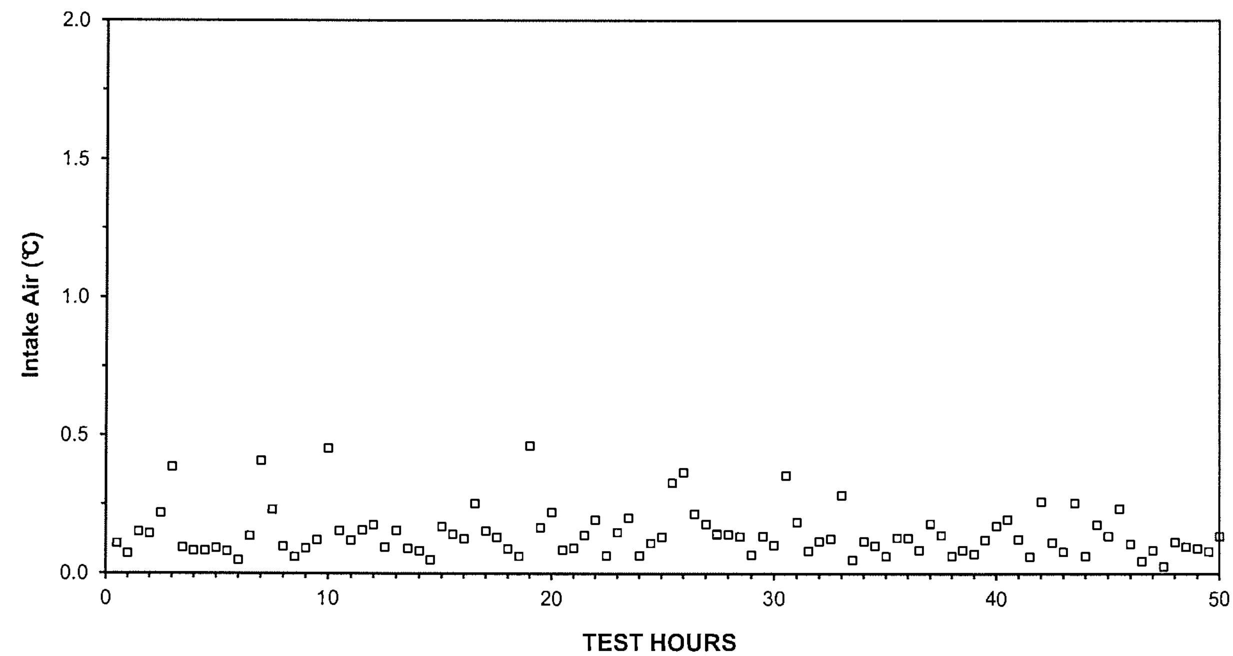
Test Number Is: Stand - Stand Run No. - Engine No.

INTAKE AIR TEMPERATURE vs TEST HOURS

Process Mean
Xav = 31.9



Process Variability (s)
Sav = 0.1



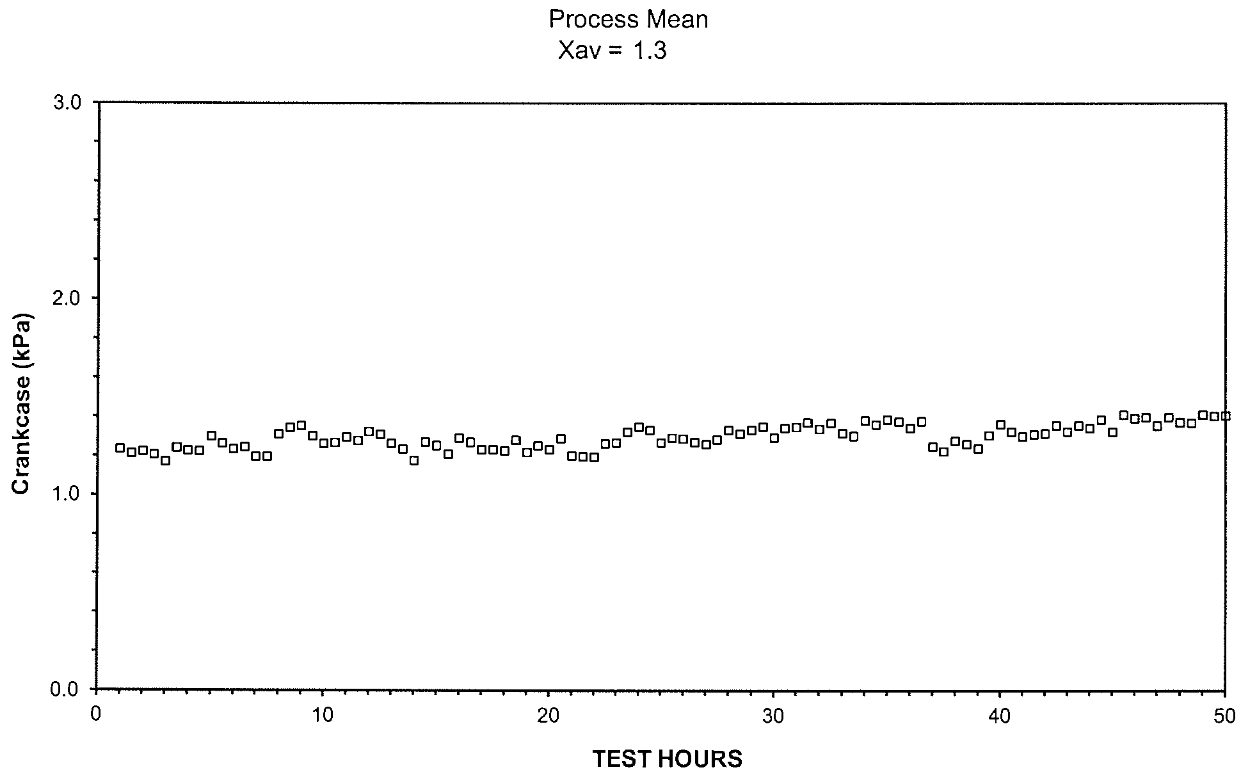
C2 - 12

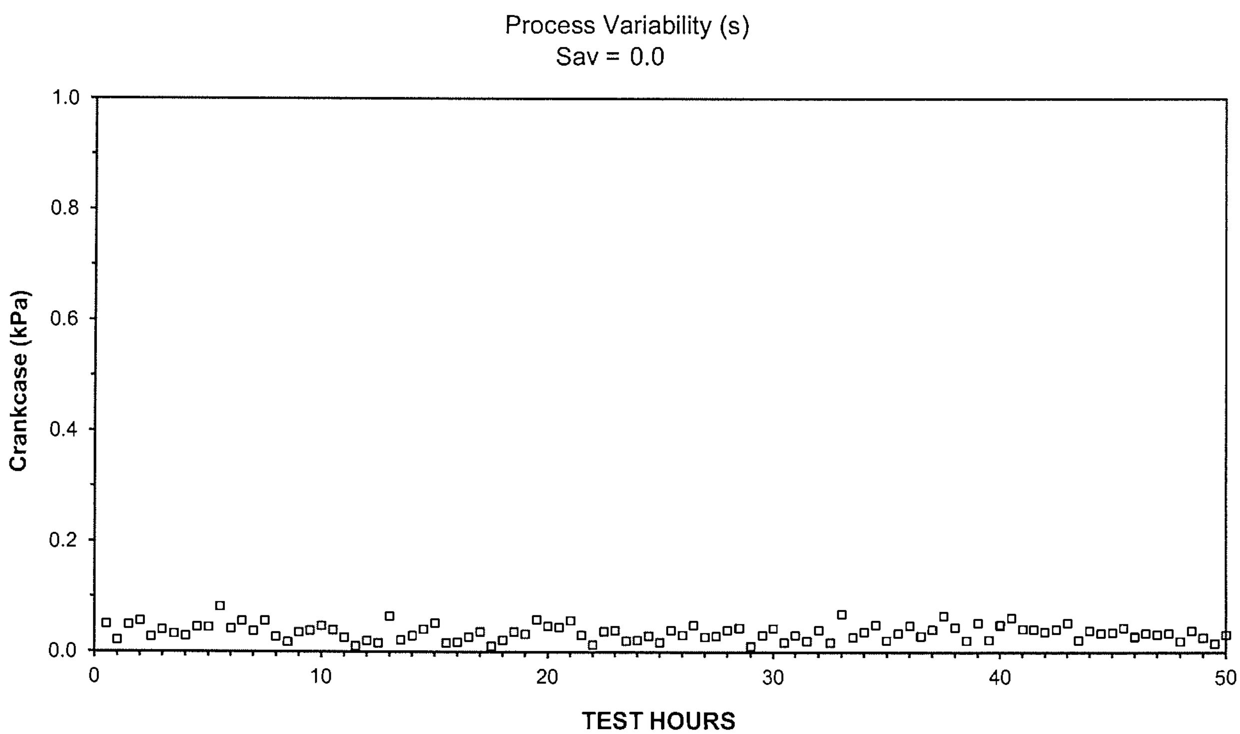
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 11

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

***Test Number Is: Stand - Stand Run No. - Engine No.**

CRANKCASE PRESSURE vs TEST HOURS





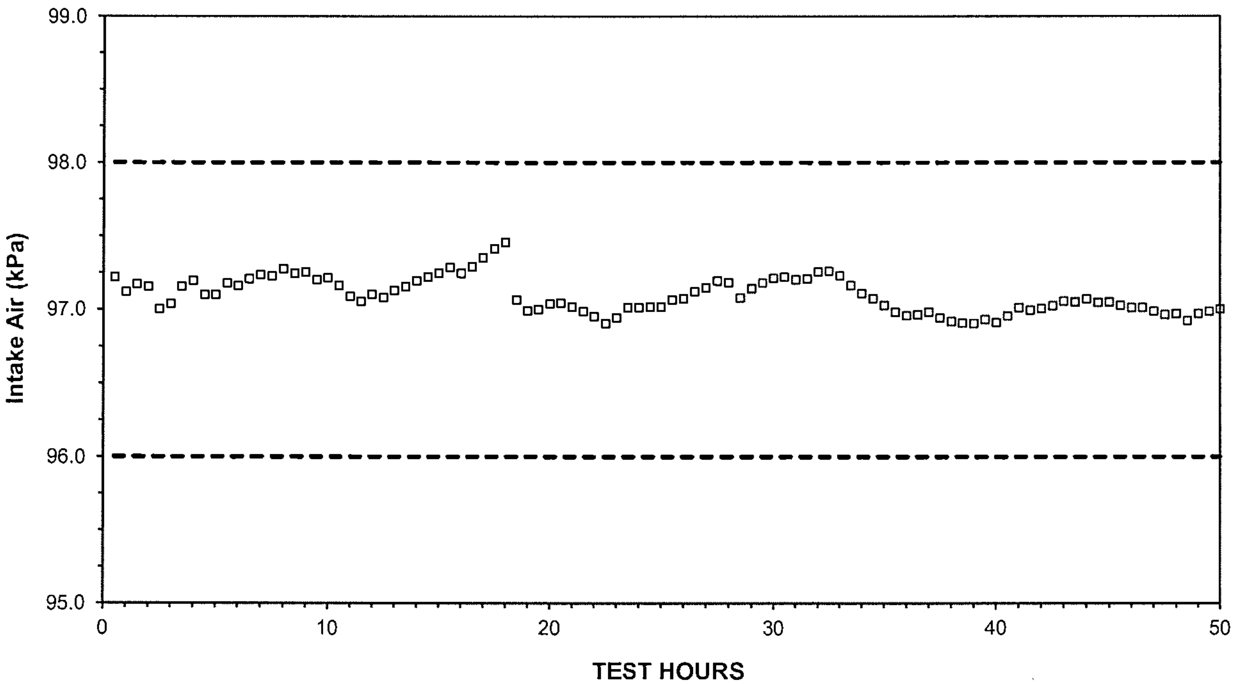
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 12

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

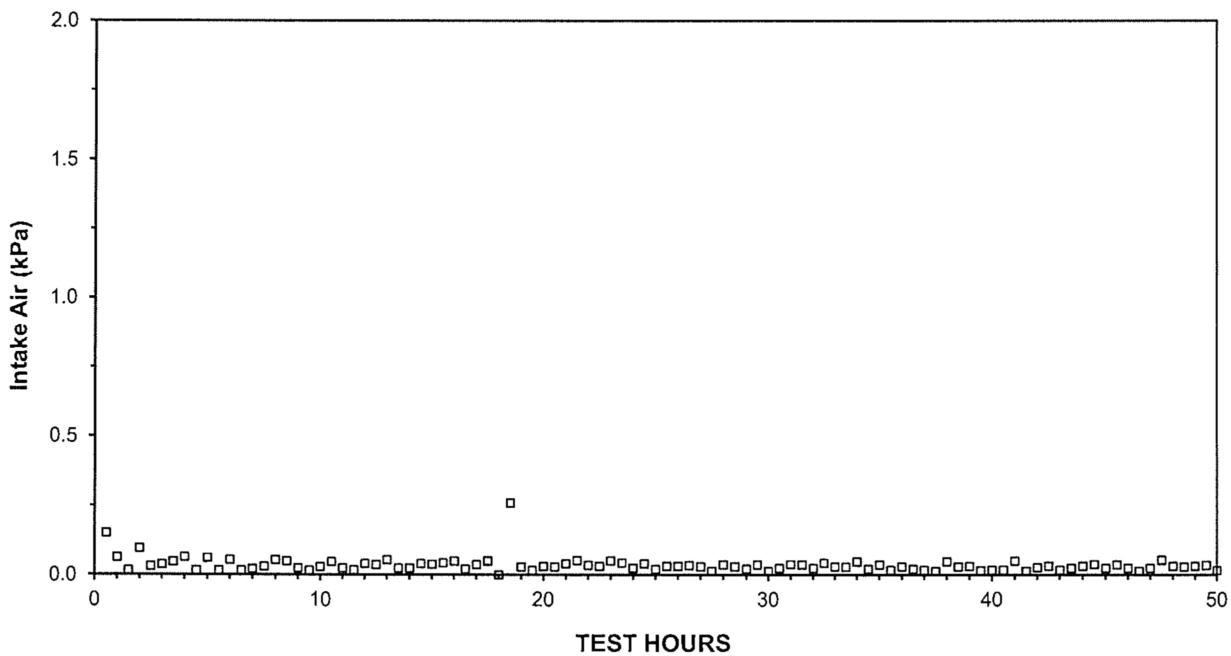
Test Number Is: Stand - Stand Run No. - Engine No.

INTAKE AIR PRESSURE vs TEST HOURS

Process Mean
Xav = 97.1



Process Variability (s)
Sav = 0.0



C2 - 14

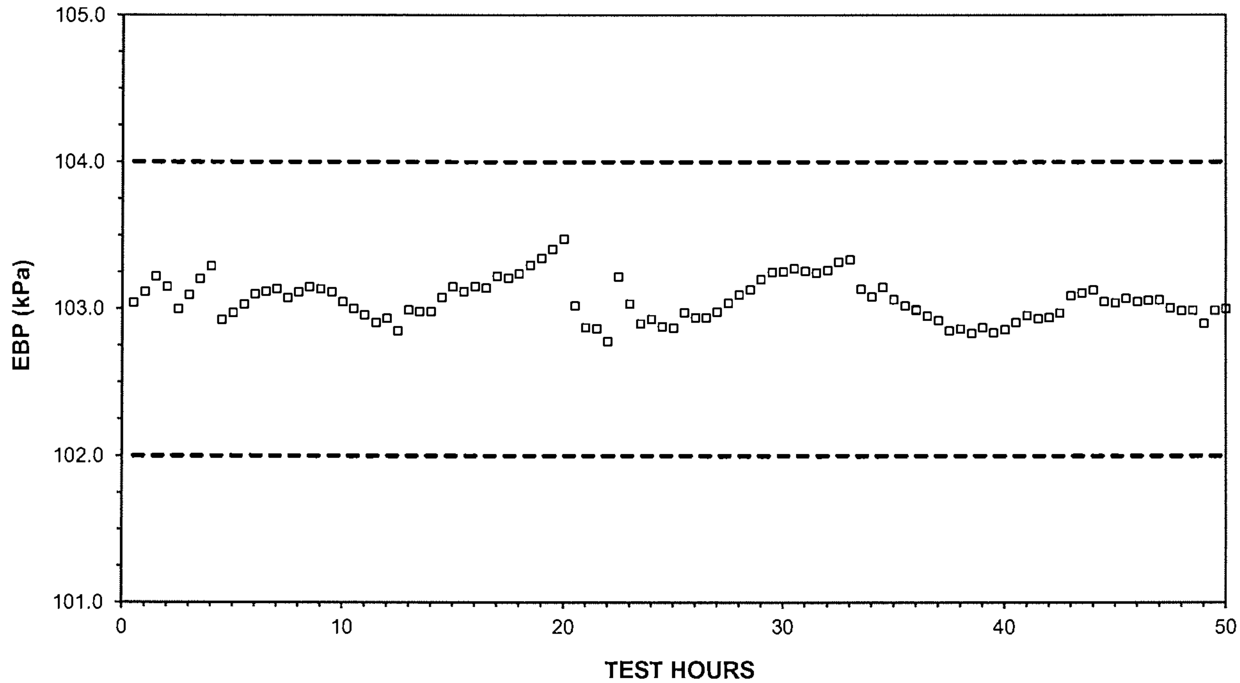
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 13

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

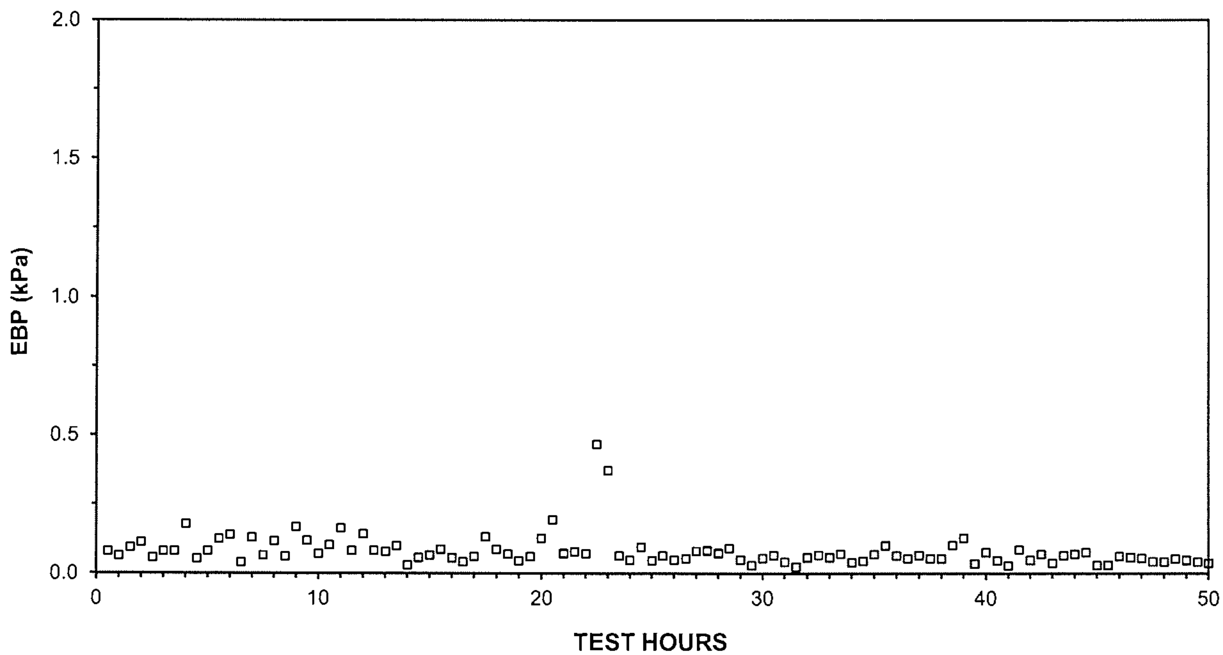
Test Number Is: Stand - Stand Run No. - Engine No.

EXHAUST BACK PRESSURE vs TEST HOURS

Process Mean
Xav = 103.1



Process Variability (s)
Sav = 0.1



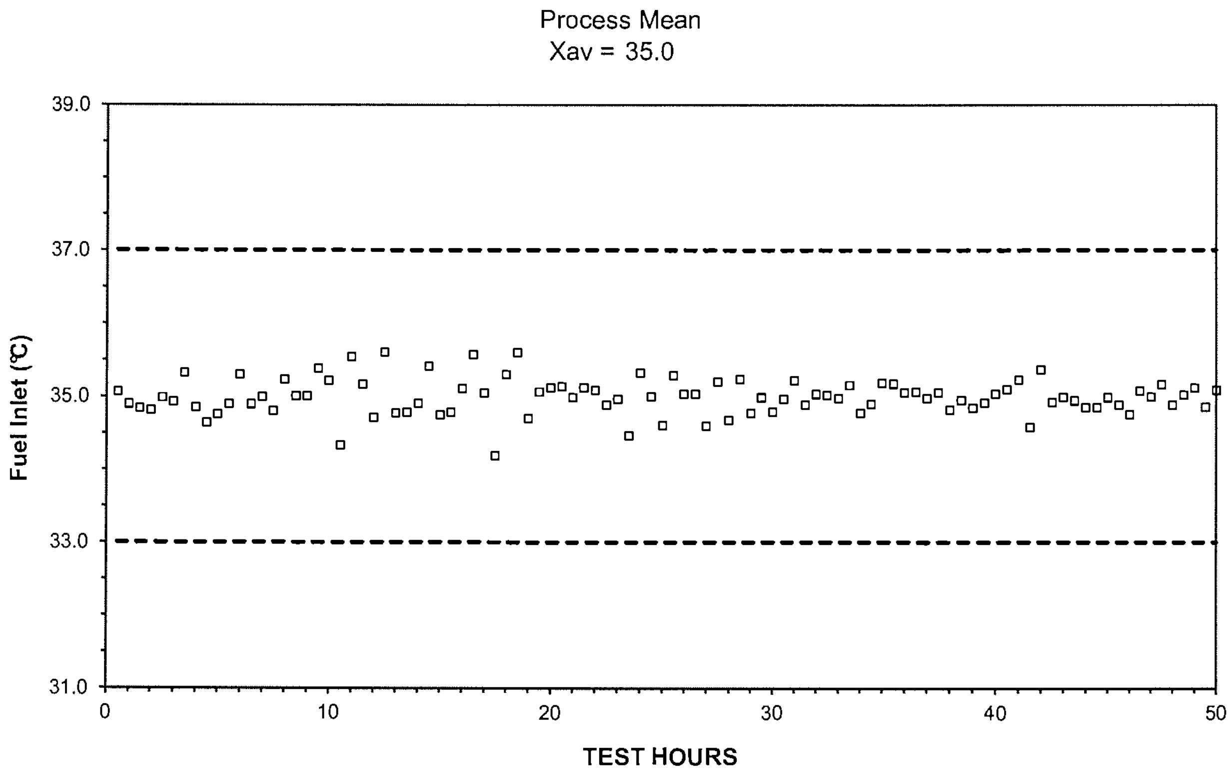
C2 - 15

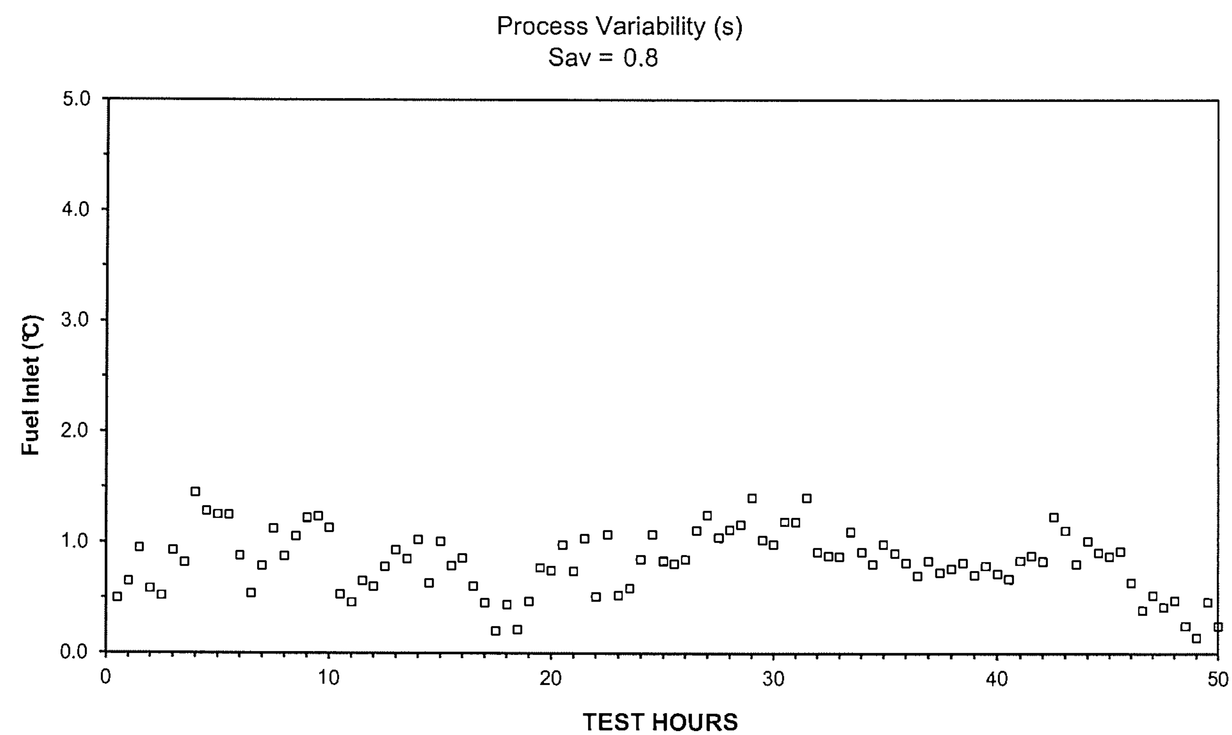
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 14

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

Test Number Is: Stand - Stand Run No. - Engine No.

FUEL INLET TEMPERATURE vs TEST HOURS





C2 - 16

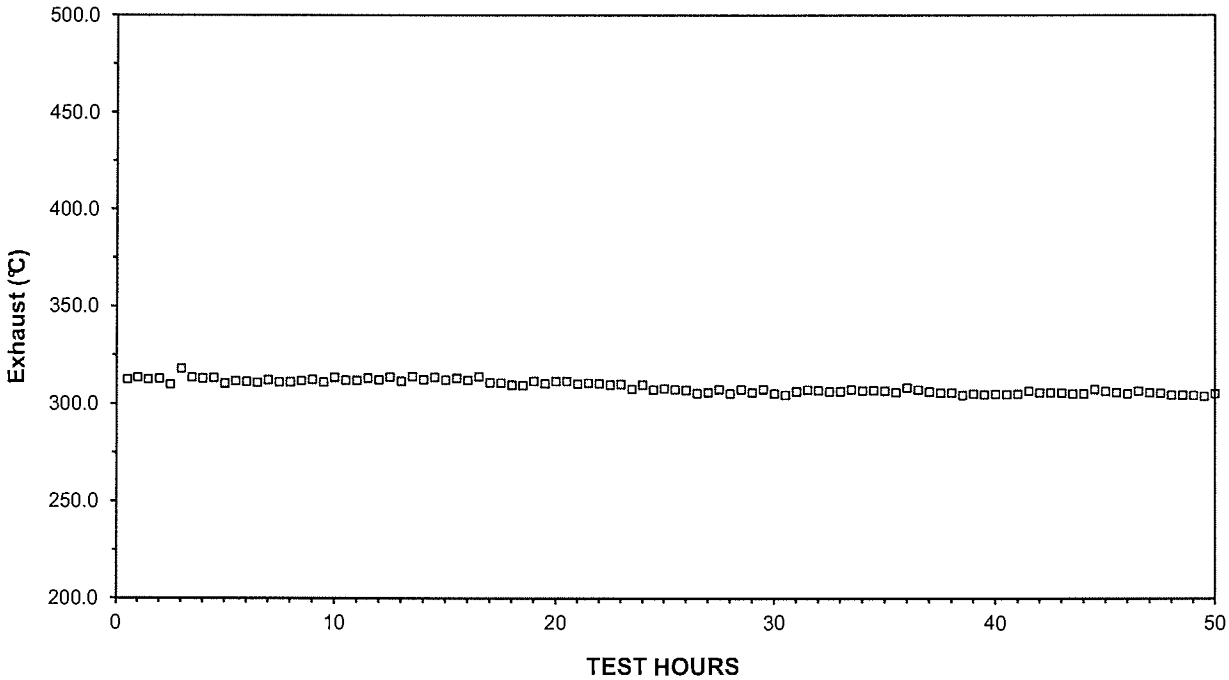
ROLLER FOLLOWER WEAR TEST
Operational Data Summary
Form 15

Laboratory: SR	EOT Date: 20120206
Test Number: 65-405-222-10	
Oil Code: LO-271510	
Formulation/Stand Code:	

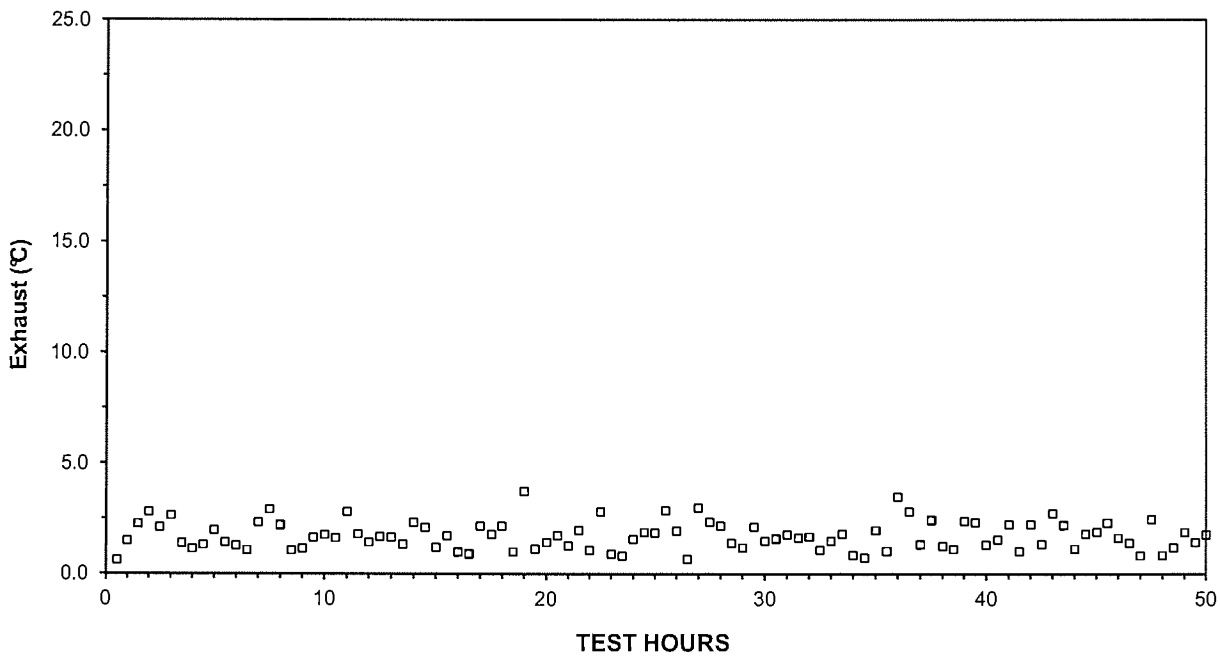
Test Number Is: Stand - Stand Run No. - Engine No.

EXHAUST TEMPERATURE vs TEST HOURS

Process Mean
Xav = 308.9



Process Variability (s)
Sav = 1.7



C2 - 17

D 5966
Roller Follower Wear Test
Operational Summary
Form 16

Laboratory: SR	EOT Date: 20120206
Test Number: * 65-405-222-10	
Oil Code: LO-271510	
Formulation / Stand Code:	

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Test Parameter	Specification		Average	Std. Dev.	Minimum	Maximum
Engine Speed, r/min	6.2L Engine 1000 ± 5	6.5L Engine 1000 ± 5	1000.0	0.1	1000.0	1001.0
Torque, N-m	Record	Record	335.8	1.6	332.6	340.4
Fuel Flow, kg/h	9.0 ± 0.1	9.4 ± 0.1	9.4	0.0	9.4	9.4
Total Oil Consumption, kg	Record	Record	3.9			

Test Parameter	Specification	Average	Std. Dev.	Minimum	Maximum
Coolant Out, °C	120 ± 2	120.0	0.1	119.6	120.2
Coolant In, °C	Report Only	111.6	0.1	111.3	111.9
Main Oil Gallery, °C	120 ± 2	120.0	0.0	119.9	120.1
Fuel In, °C	35 ± 2	35.0	0.2	34.2	35.6
Intake Air, °C	32 ± 2	31.9	1.4	28.9	34.0
Oil Sump, °C	Report	128.2	0.3	127.5	128.7
Exhaust, °C	Report	308.9	3.2	304.0	318.1

Pressures	Specification	Average	Std. Dev.	Minimum	Maximum
Crankcase, kPa	Report	1.3	0.1	1.4	1.2
Back Pressure, kPa	103 ± 1	103.1	0.1	102.8	103.5
Intake Air, kPa	97 ± 1	97.1	0.1	96.9	97.5

D 5966
Roller Follower Wear Test
Oil Analysis
Form 17

Laboratory: SR	EOT Date: 20120206
Test Number: * 65-405-222-10	
Oil Code: LO-271510	
Formulation / Stand Code:	

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Hours	Viscosity, cSt @ 100°C	% SOOT
NEW	8.61	0.2
025	10.29	2.6
050	11.65	4.5

Hours	Elements						
	Al	Cr	Cu	Fe	Pb	Si	Sn
NEW	1	0	0	1	0	6	0
025	2	2	2	70	5	6	0
050	2	4	3	151	11	7	1

Average Bosch Smokes	6.5
Average BSFC	0.268 kg/kW-h

D 5966
Roller Follower Wear Test
Unscheduled Downtime & Maintenance Summary
Form 18

Laboratory: SR	**EOT Date:** 20120206
Test Number: * 65-405-222-10	
Oil Code: LO-271510	
Formulation / Stand Code:	

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Number of Downtime Occurrences: 0

Test	Date	Downtime	Reasons
Total Downtime		0:00	

Other Comments

Number of Comment Lines: 0

D 5966
Roller Follower Wear Test
Test Fuel Analysis (Last Batch)
Form 21

Laboratory: SR	**EOT Date:** 20120206
Test Number: * 65-405-222-10	
Oil Code: LO-271510	
Formulation / Stand Code:	
Supplier: Chevron Phillips	**Batch Identifiers:** 11JPPC901

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Measurement	Specifications	Analysis	Test Method
Total Sulfur, % Weight	0.03 - 0.05	0.04	D 2622
Gravity, °API	32 - 36	35.1	D 287
Hydrocarbon Composition			
Aromatics, % Vol.	28 - 35	30.7	D 5186
Olefin	Report	4.3	D 1319
Saturates	Report	65.0	D 1319
Cetane Index	42 - 48	44.0	D 4737
Cetane No.	42 - 48	46.0	D 613
Copper Strip Corrosion	3 Maximum	1A	D 130
Flash Point, °C	54 Minimum	63	D 92
Cloud Point, °C	-12 Maximum	-21	D 2500
Pour Point, °C	-18 Maximum	-27	D 97
Carbon Residue on 10% Residuum, %	0.35 Maximum	0.10	D 524 (10% Bottoms)
Water & Sediment, % Vol.	0.05 Maximum	0.00	D 2709
Ash, % Wgt.	0.01 Maximum	0.000	D 482
Viscosity, cSt @ 40°C	2.0 - 3.2	2.4	D 445
Distillation, °C			
IBP	177 - 199	173	D 86
10%	210 - 232	206	D 86
50%	249 - 277	252	D 86
90%	299 - 327	326	D 86
EP	327 - 360	361	D 86

D 5966
Roller Follower Wear Test
Characteristics of the Data Acquisition System
Form 22

Laboratory: SR	EOT Date: 20120206
Test Number: * 65-405-222-10	
Oil Code: LO-271510	
Formulation / Stand Code:	

Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.

Parameter (1)	Sensing Device (2)	Calibration Frequency (3)	Record Device (4)	Observation Frequency (5)	Record Frequency (6)	Log Frequency (7)	System Response (8)
Temperatures							
Main Oil G.	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Fuel In.	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Intake Air	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Oil Sump	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Exhaust	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Coolant Out	Thermocouple	Every ref test	C/D	0	0	1 per min	2.0s
Other							
Fuel Flow	Mass Flow	Every ref test	C/D	0	0	1 per min	2.5s
Engine RPM	Magnetic	Every ref test	C/D	0	0	1 per min	0.5s
Load	Strain Gage	Every ref test	C/D	0	0	1 per min	0.5s
Intake Press.	Mechanical	Every ref test	C/D	0	0	1 per min	N/A
Exhaust Press.	Mechanical	Every ref test	C/D	0	0	1 per min	N/A
Oil Gallery Press.	Mechanical	Every ref test	C/D	0	0	1 per min	N/A

Legend:

(1) Operating Parameter
(2) The Type of Device Used to Measure Temperature, Pressure or Flow
T/C - Thermocouple
(3) Frequency at Which the Measurement System is Calibrated
(4) The Type of Device Where Data is Recorded
LG - Handlog Sheet
DL - Automatic Data Logger
SC - Strip Chart Recorded
C/M - Computer, Using Manual Data Entry
C/D - Computer, Using Direct I/O Entry
(5) Data are Observed but Only if Recorded Off Spec.
(6) Data are Recorded but are not Retained at EOT
(7) Data are Logged as Permanent Record, Note Specify if:
SS - Snapshot Taken at Specified Frequency
AG/X Average of X Data Points at Specified Frequency
(8) Time for the Output to Reach 63.2% of Final Value for Step Change at Input

D5966
Roller Follower Wear Test

Laboratory: SR	**EOT Date:** 20120206
Test Number: * 65-405-222-10	
Oil Code: LO-271510	
Formulation / Stand Code:	

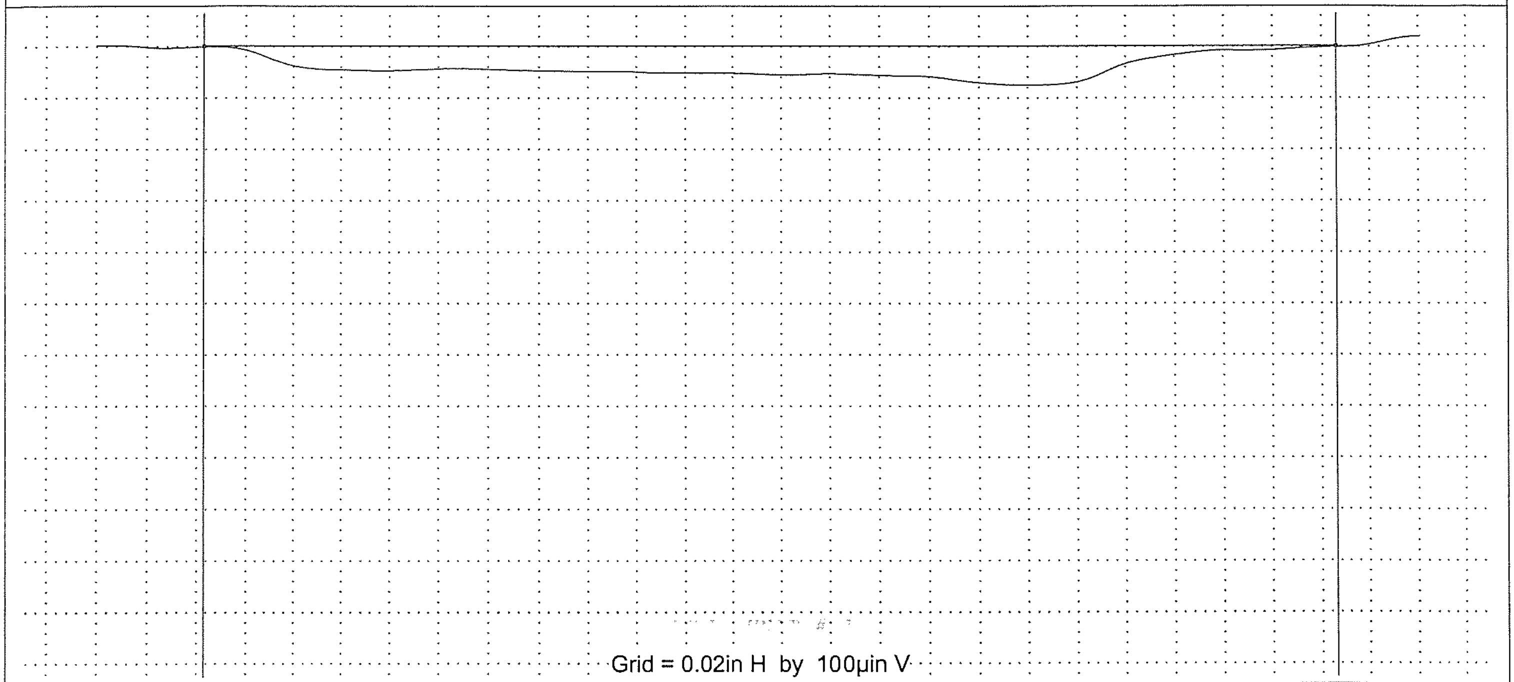
**Test Number is:* *Stand - Stand Run No. - Engine No. - Engine Run No.*

Appendix A

Roller Follower Wear Test Traces

1. Profilometer Traces 1-8 (Right and Left) (8 pages)

Profiles: Waviness



Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:13 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R1
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

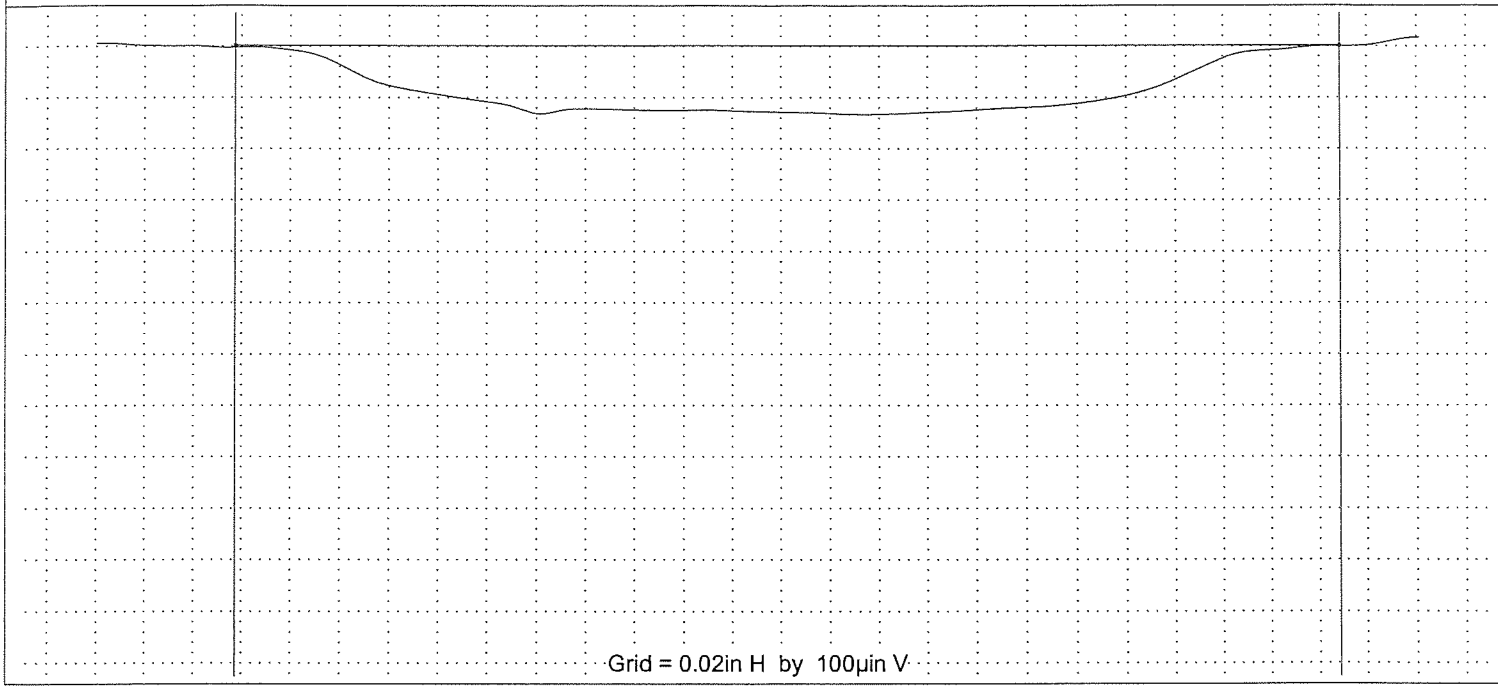
Run 65-405-222-10

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	75.2	µin

Parameters

Profiles: Waviness



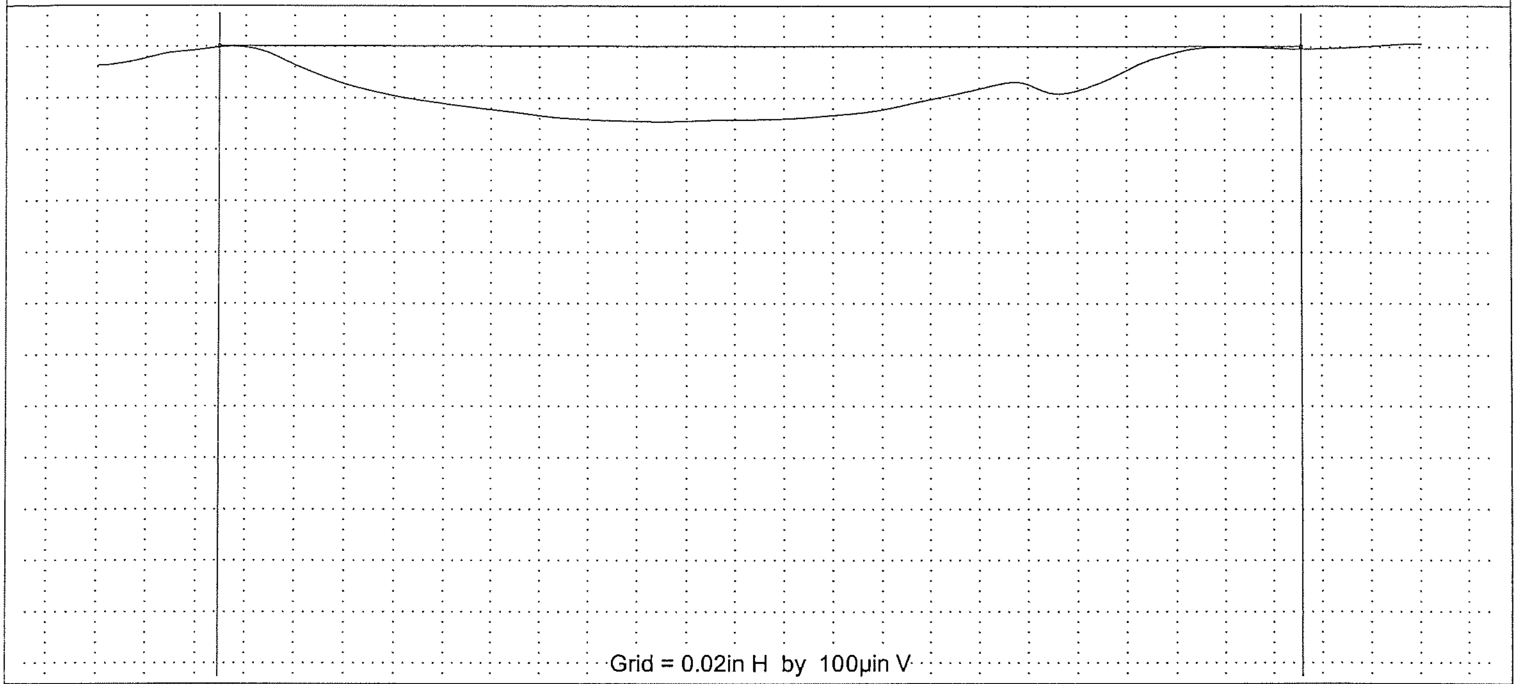
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:15 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R2
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter
Description

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	133.3	µin

Profiles: Waviness



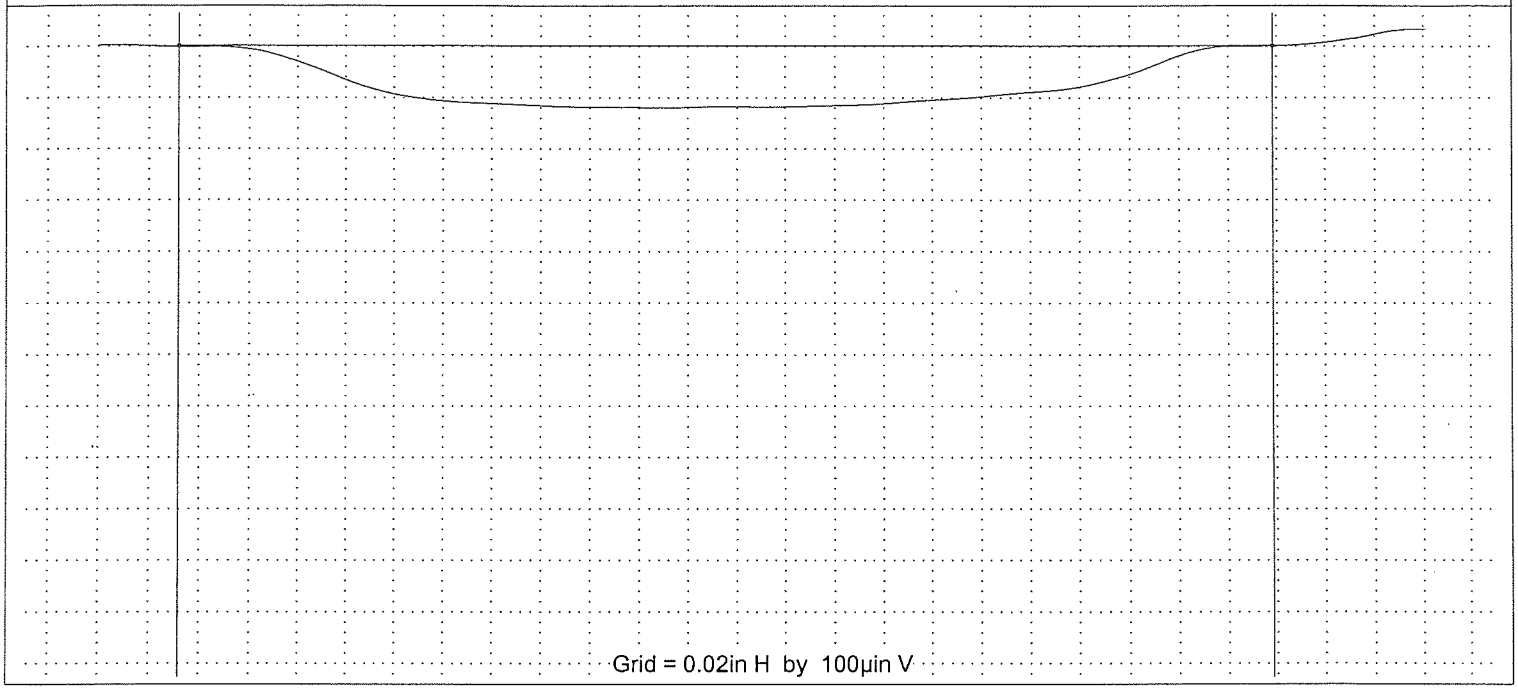
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:17 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R3
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	145.9	µin

Profiles: Waviness



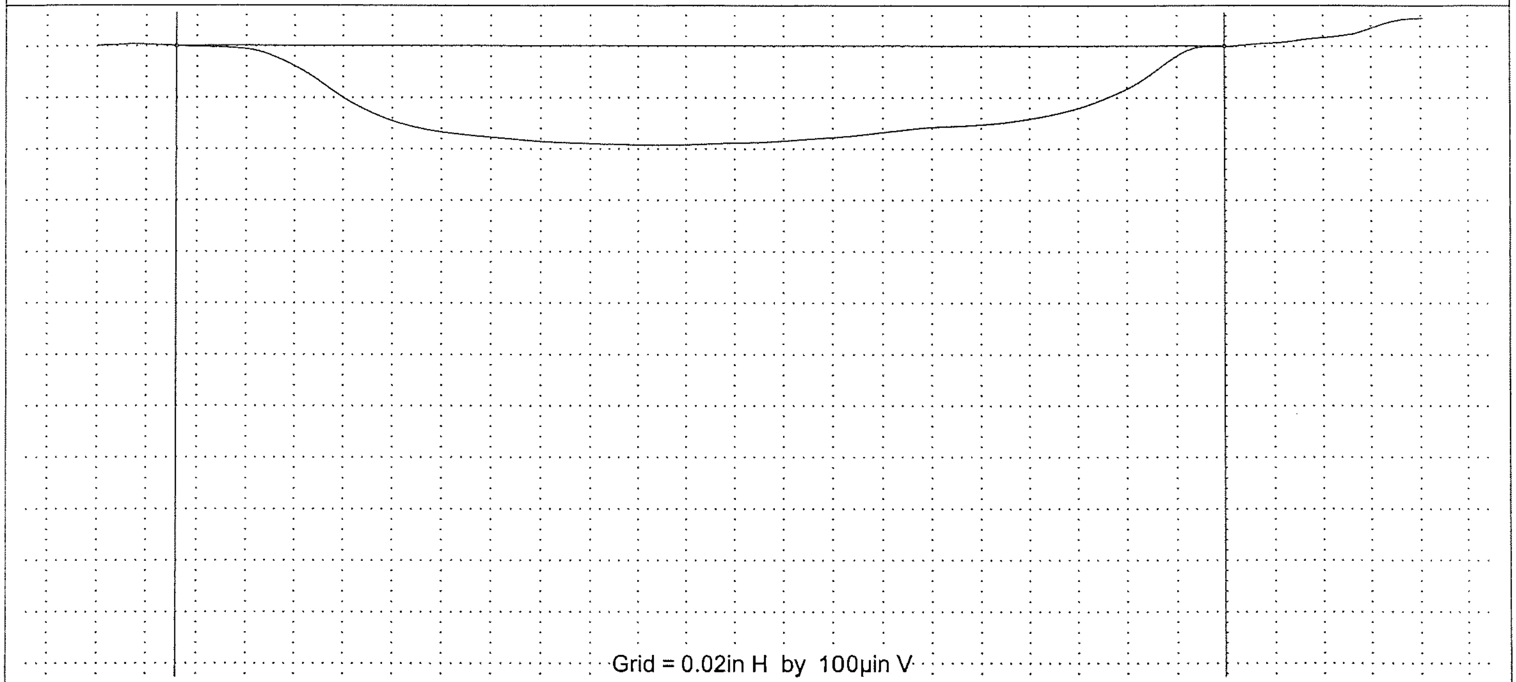
Settings

```
Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:19 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R4
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter
```

Parameters

```
 PARAMETER    VALUE     UNITS
 ---------    -----     -----
Summary
 Standards System = ANSI/ASME B46.1 1995
Waviness Parameters:
 Wt           120.5     µin
```

Profiles: Waviness



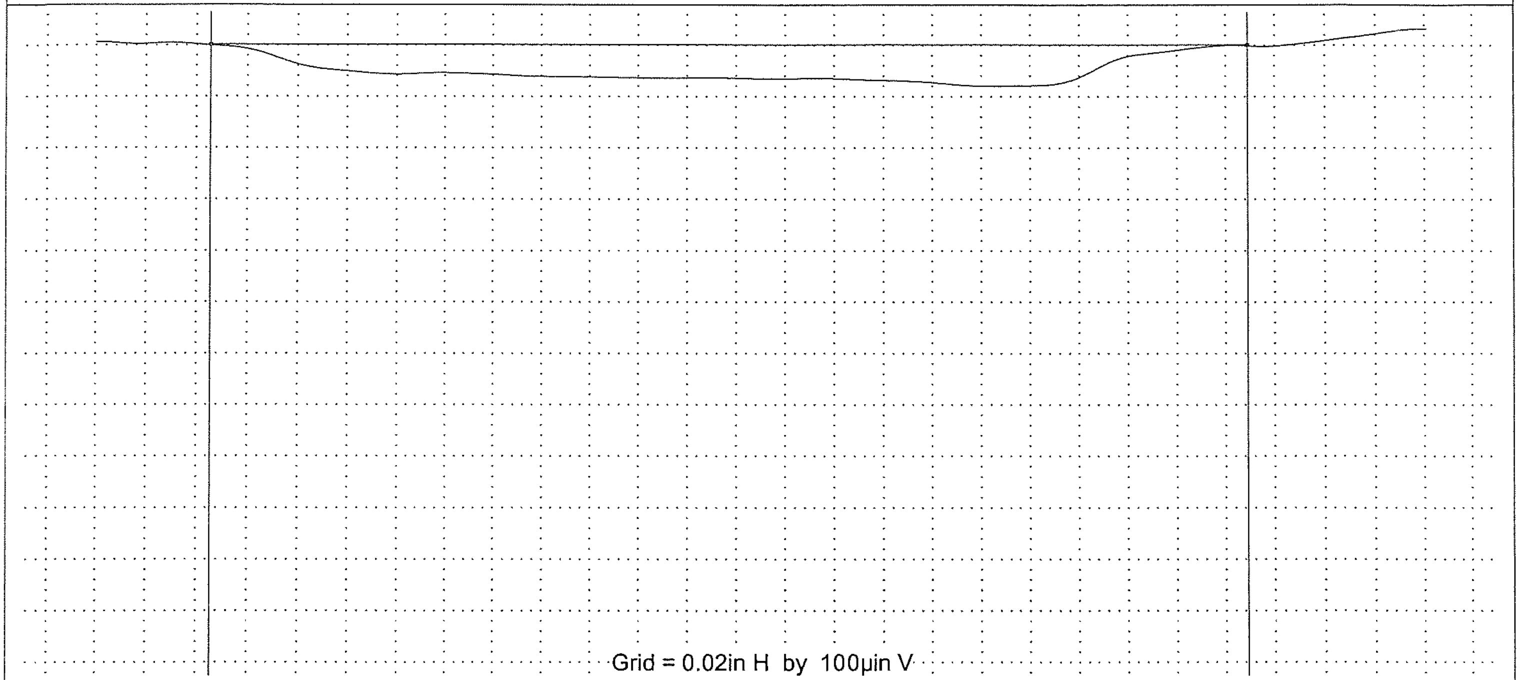
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:22 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 μin
Description
  RFWT, Pin R5
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 μin
  High Spot Count Threshold: 19.7 μin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 μin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	193.6	μin

Profiles: Waviness



Settings

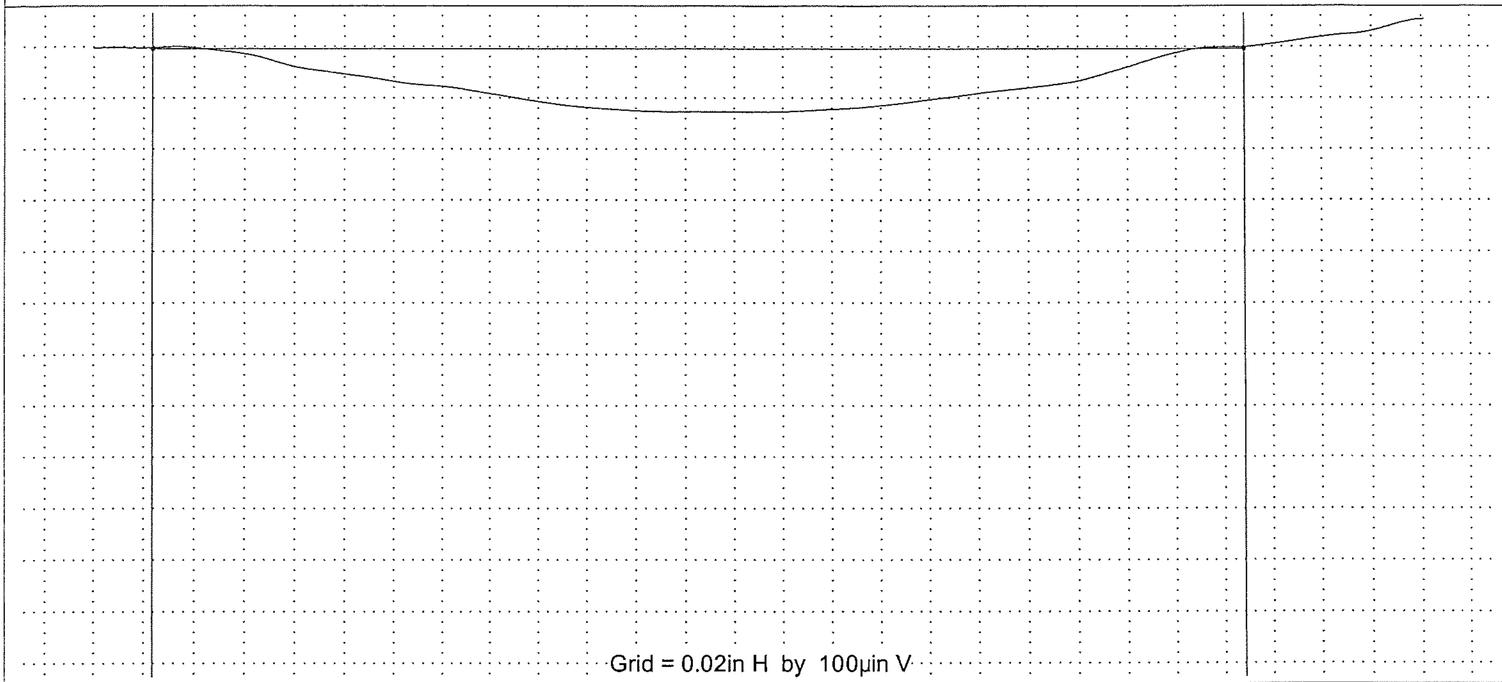
Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:24 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R6
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

RFWT, Pin R6

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	79.9	µin

Profiles: Waviness



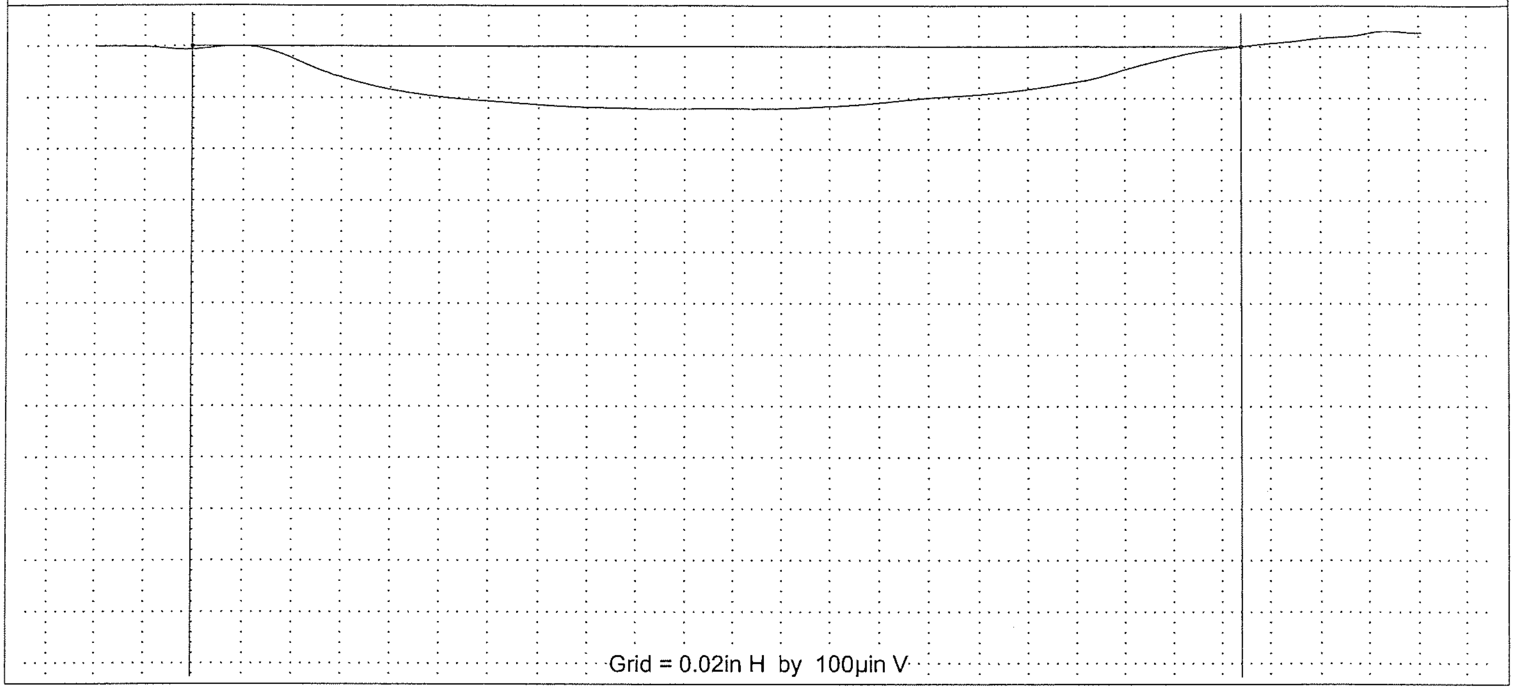
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:27 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R7
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.P
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	127.8	µin

Profiles: Waviness

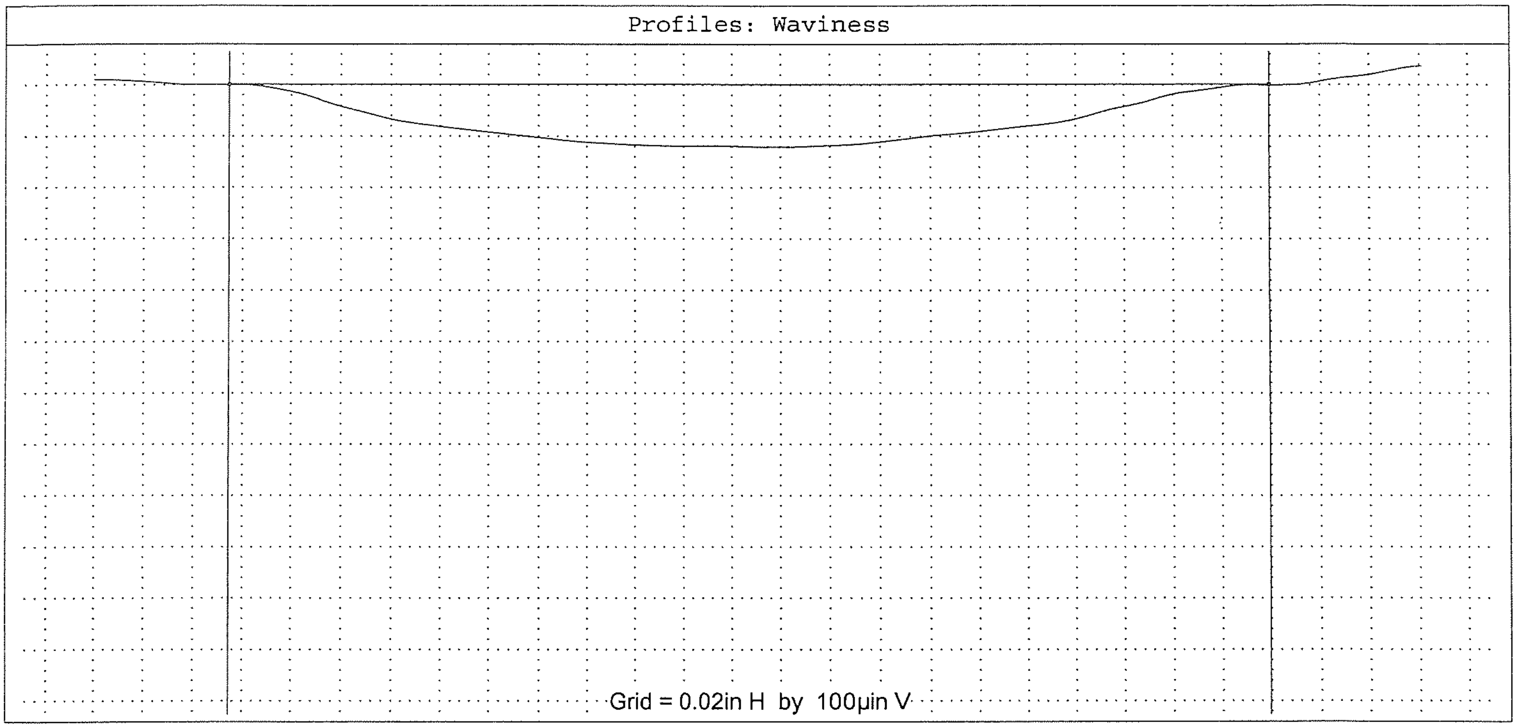


Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:29 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R8
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.P
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	121.7	µin



Settings

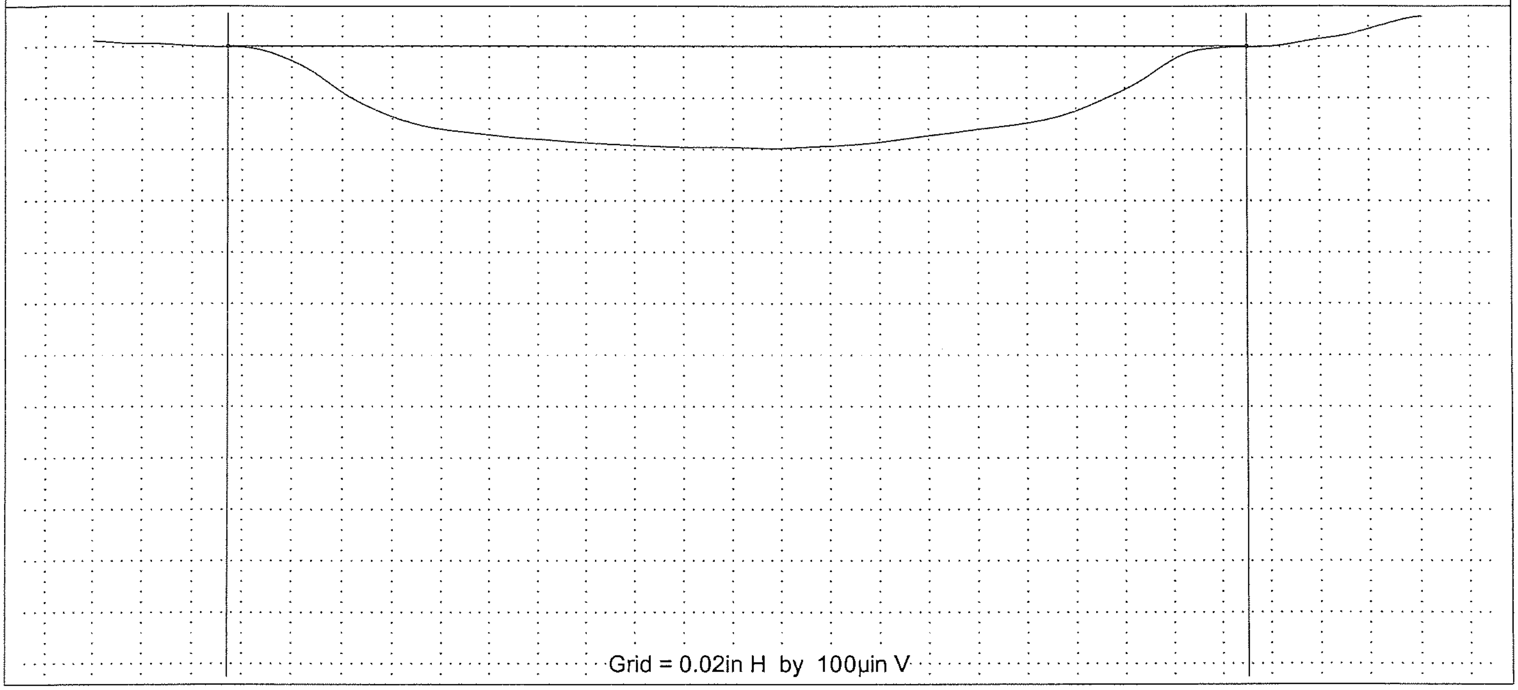
Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:30 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L1
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.F
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Description

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	121.3	µin

Profiles: Waviness



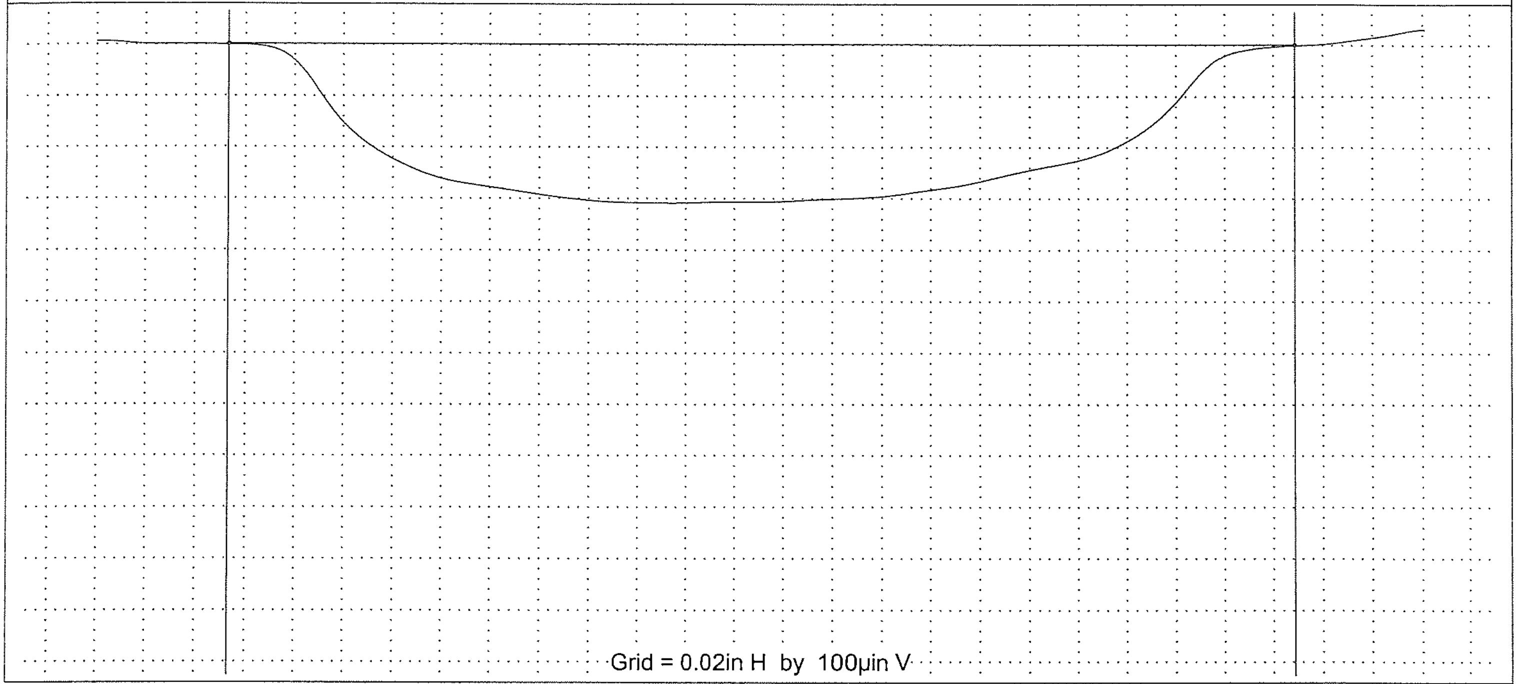
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:34 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L2
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	197.8	µin

Profiles: Waviness



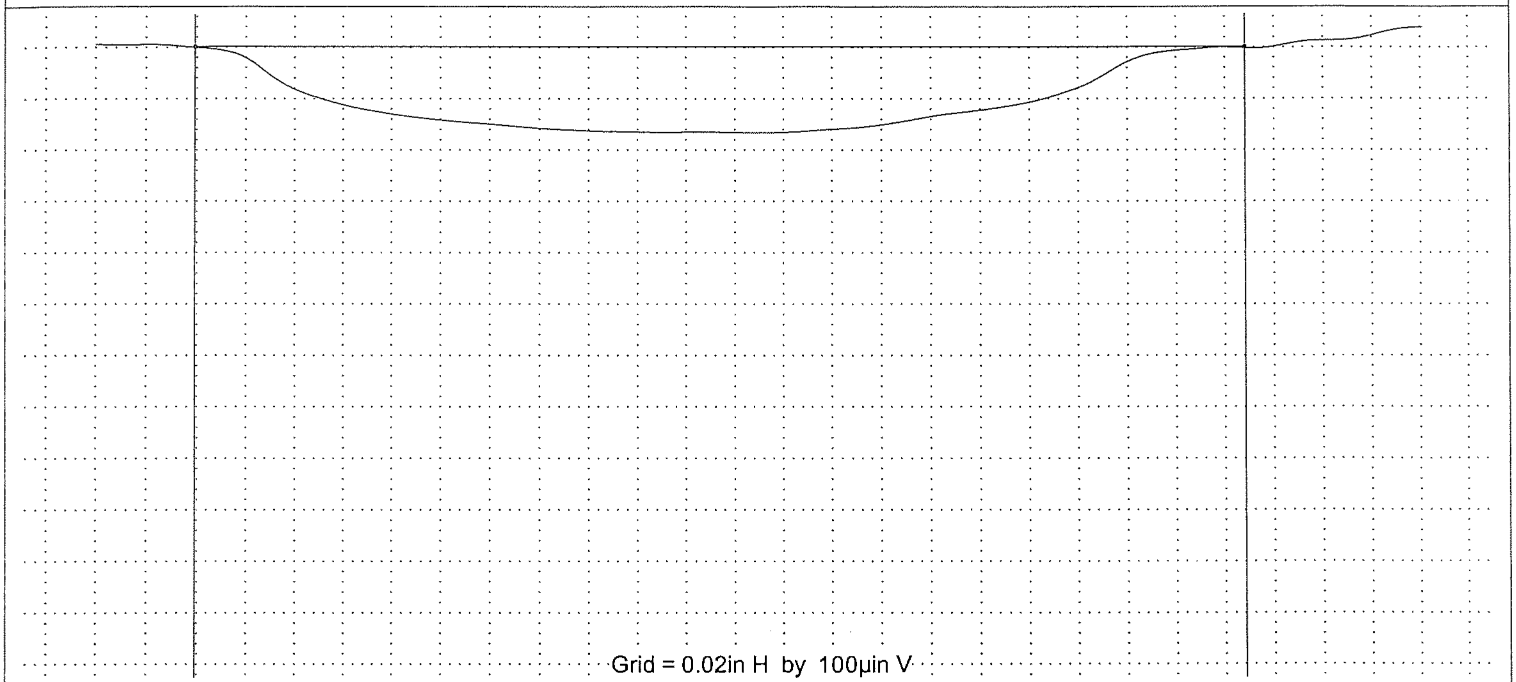
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:35 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L3
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.P
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	308.3	µin

Profiles: Waviness



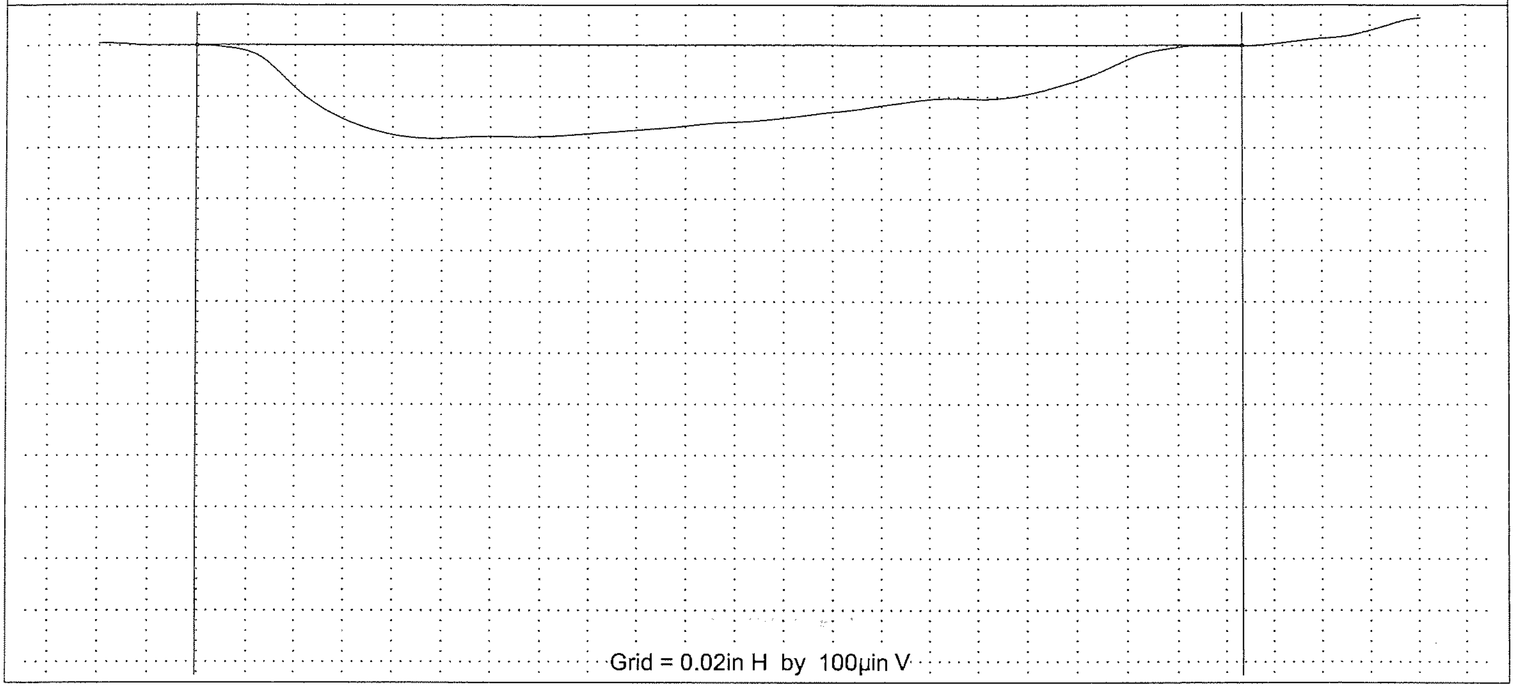
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:37 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 μin
Description
  RFWT, Pin L4
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 μin
  High Spot Count Threshold: 19.7 μin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 μin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	166.2	μin

Profiles: Waviness



Settings

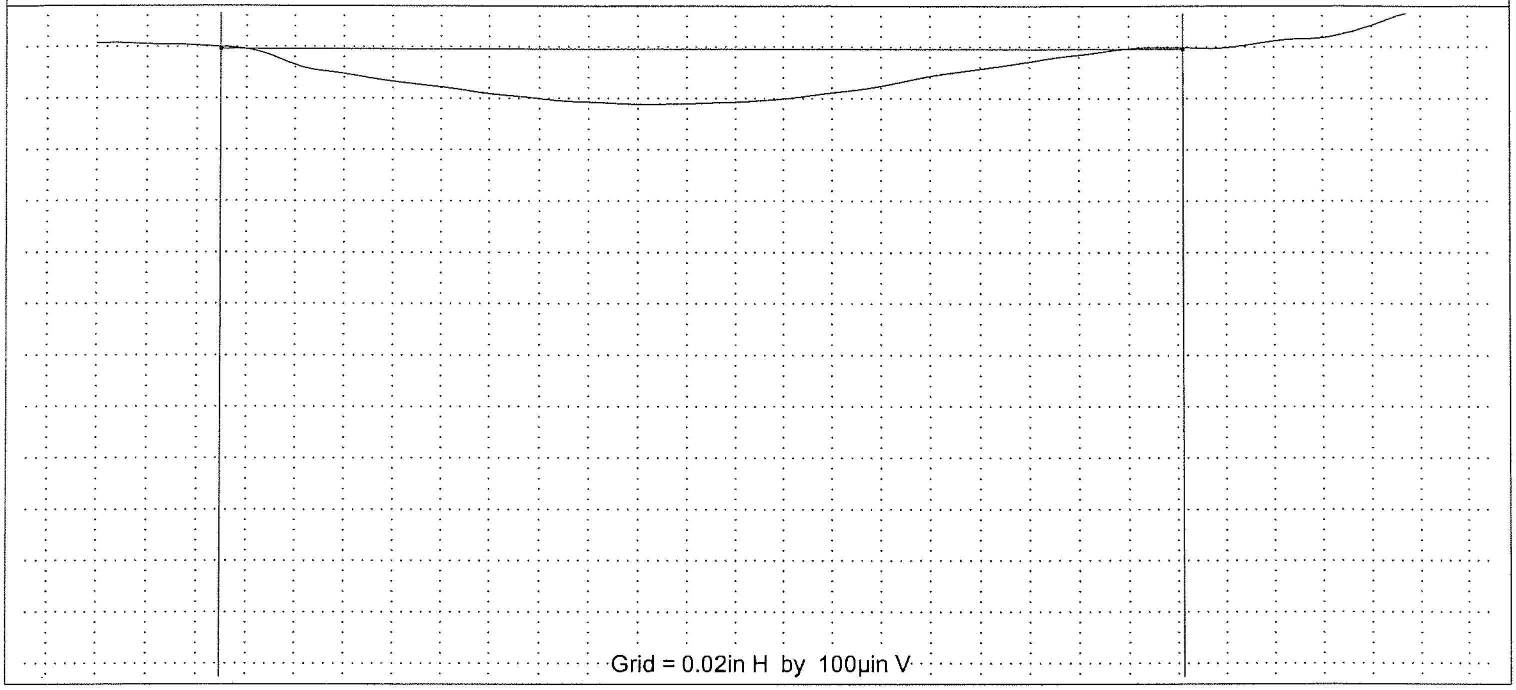
Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:40 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L5
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	182.4	µin

C2 - 36

Profiles: Waviness



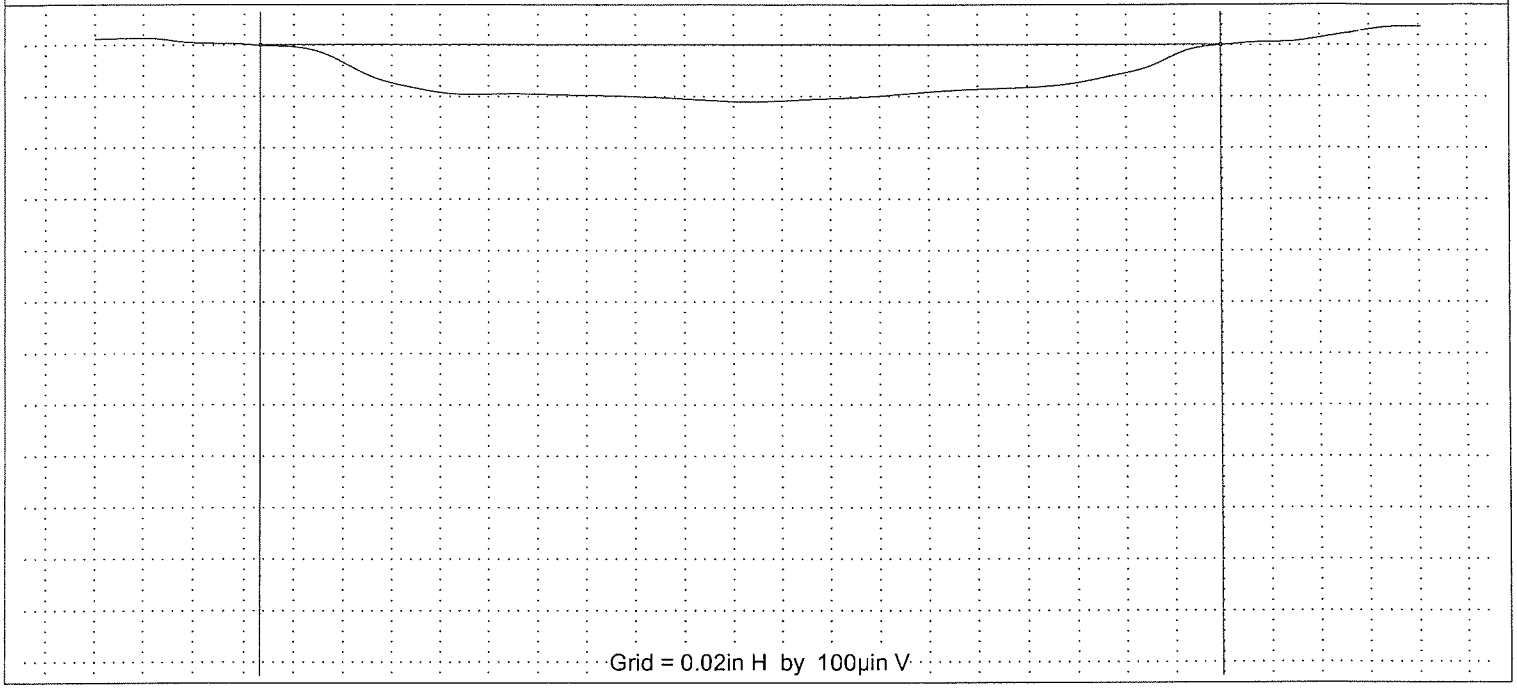
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:44 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L6
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	111.7	µin

Profiles: Waviness



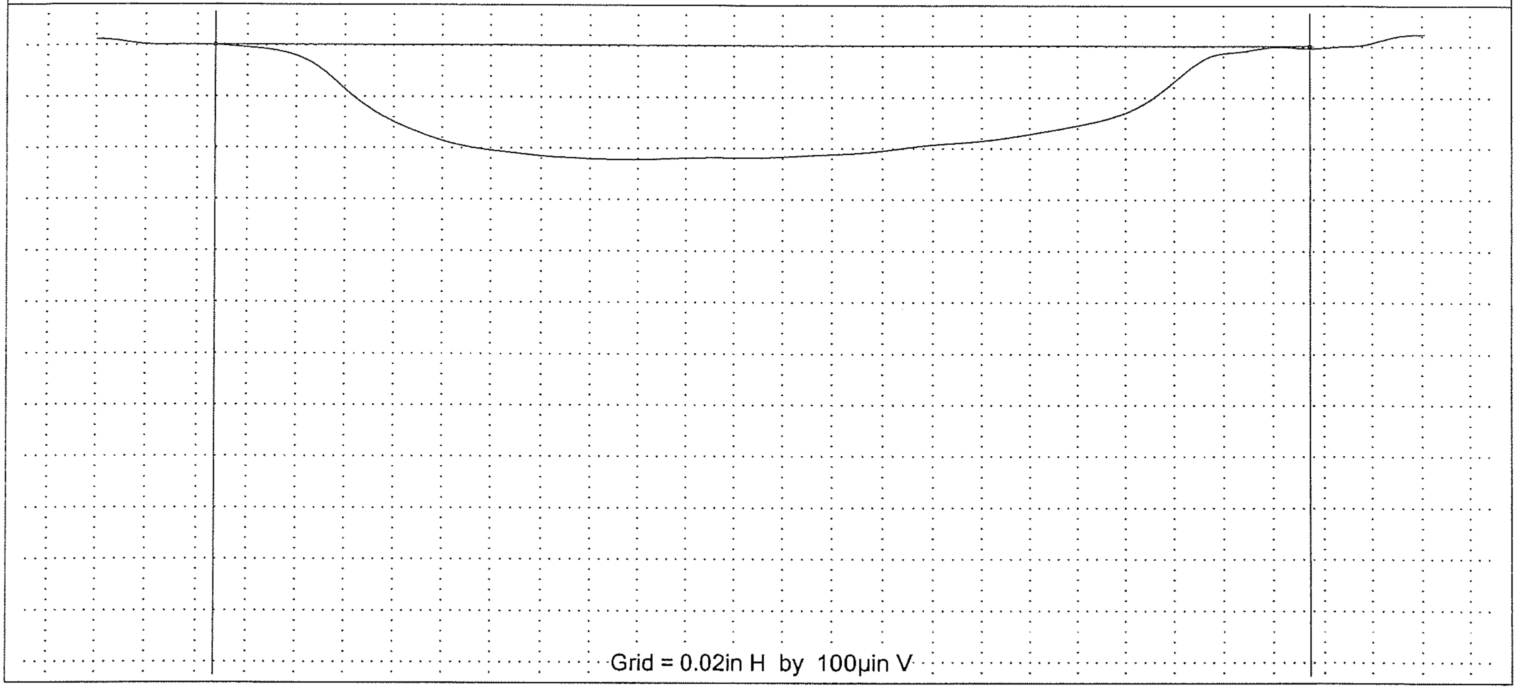
Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:45 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L7
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	111.1	µin

Profiles: Waviness



Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:10 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L8
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

PARAMETER	VALUE	UNITS
Summary		
Standards System = ANSI/ASME B46.1 1995		
Waviness Parameters:		
Wt	222.4	µin

Laboratory:	SR	**EOT Date:**	20120206
Test Number: *	65-405-222-10		
Oil Code:	LO-271510		
Formulation / Stand Code:			

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

Appendix B

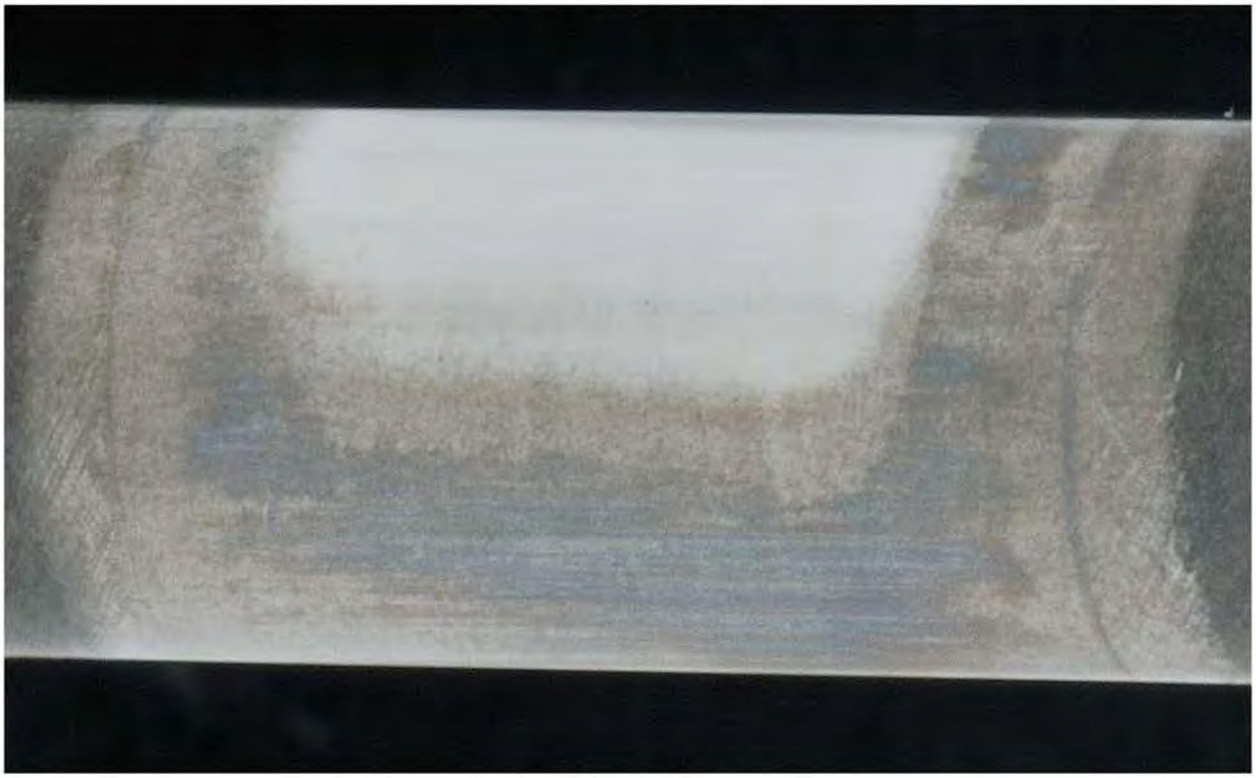
Roller Follower Wear Test Photographs

1. Roller Follower Axle Pin Wear Best
2. Roller Follower Axle Pin Wear Worst

Roller Follower Wear Test

Laboratory:	SR	Oil Code:	LO-271510
Test Stand No.:	65	Test No.:	65-405-222-10
Laboratory Oil Code:	271510	Test Hours:	50
Formulation / Stand Code:			

Roller Axle Wear



Best 1R

Roller Follower Wear Test

Laboratory:	SR	**Oil Code:**	LO-271510
Test Stand No.:	65	**Test No.:**	65-405-222-10
Laboratory Oil Code:	271510	**Test Hours:**	50
Formulation / Stand Code:			

Roller Axle Wear

Worst 3L

APPENDIX – D1 (Part 1)
TYPE C-4 GRAPHITE CLUTCH FRICTION TEST
LO268869

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HEAVY-DUTY TRANSMISSION FLUID

TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

ARMY LAB

Oil Code:
LO268869

Test Number:
C4-3-1341

October 14, 2011

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluid Evaluation

VIII. Graphite Clutch Friction Test

Test Laboratory:	SwRI	Lab Fluid Code:	LO-268869
Test Number:	C4-3-1341	Sponsor Fluid Code:	LO268869
Friction Plate Batch:	LOT 44	Completion Date:	10/14/11
Steel Plate Batch:	10/9/2008		

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0970	0.0818

	Before	After
Pack Clearance	0.5334	0.5588

Reference Tests

Test Number	Test Date	Test Fluid
C4-0-1304	12/09/10	PASS REF-L-06-04
C4-0-1315	03/30/11	MIL-PRF-2104H
C4-0-1338	10/05/11	MIL-PRF-2104H

	New	EOT
Viscosity at 40°C, cSt	47.29	41.16
Viscosity at 100°C, cSt	8.81	7.80
Iron Content, ppm	2	61

D5185	New Fluid (ppm)
Ba	<1
B	<1
Ca	3419
Mg	10
P	1272
Si	2
Na	5
Zn	1874

Name: Matthew Jackson

Signature:

Title: Manager

Date: 10/25/11

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO268869**	Test Number:	**C4-3-1341**
Lab Fluid Code:	**LO-268869**	Fric. Plate Batch:	**LOT 44**
Completion Date:	**10/14/2011**	Steel Plate Batch:	**10/9/2008**

PHASE A

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
500	1.17	54	56	42	14	60	53
1000	1.18	53	56	38	18	64	55

PHASE B

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (0.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
1500	0.75	106	141	96	45	147	134
2000	0.79	100	140	88	52	146	132
2500	0.81	97	137	82	55	144	131
3500	0.84	94	131	73	58	140	128
4000	0.86	92	129	72	57	139	126
4500	0.87	91	125	71	54	142	124
5000	0.87	91	123	70	53	135	122
5500	0.86	93	121	72	49	131	120

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.75	0.86	14.67	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.090	0.067	-25.556	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.099	0.087	-12.121	F
Static Friction Coeff.	N/A	N/A	0.132	0.113	-14.394	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.138	0.123	-10.870	
0.25 Second Low Speed Coeff.	N/A	N/A	0.126	0.112	-11.111	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-GRAPHITE FRICTION TEST

Candidate Fluid: LO268869 **Test Number : C4-3-1341** **Completion Date : 10/14/2011**

Lab Fluid Code : LO-268869 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 44**

(all units in mm)

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.2660	2.1690	2.2480	2.1810	0.0970		0.0670
	120	2.2470	2.1600	2.2540	2.1830	0.0870		0.0710
	240	2.2460	2.1620	2.2640	2.1790	0.0840		0.0850
	Average					0.0893	0.0818	0.0743
STEEL SEPARATORS								
1	Top	1.7460	1.7460	1.7450	1.7450	0.0000		0.0000
	120	1.7500	1.7500	1.7500	1.7500	0.0000		0.0000
	240	1.7510	1.7510	1.7510	1.7510	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7580	1.7580	1.7580	1.7580	0.0000		0.0000
	120	1.7540	1.7540	1.7510	1.7510	0.0000		0.0000
	240	1.7560	1.7560	1.7560	1.7560	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T. NO UNUSUAL DISCOLORATION ON STEEL PLATES

(Anything Unusual)

Test Date: 10/14/2011

Operator's Name: JOE M

Reviewed By (Signature and Date)

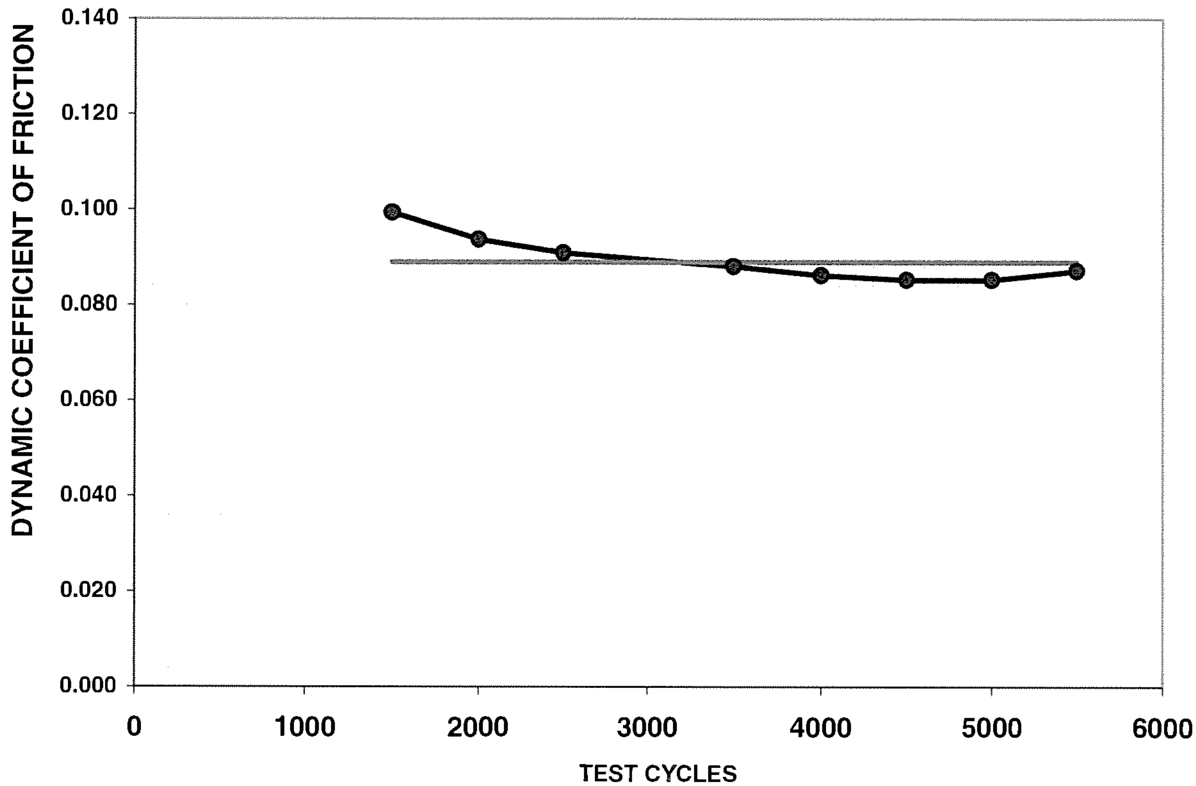
10/24/11

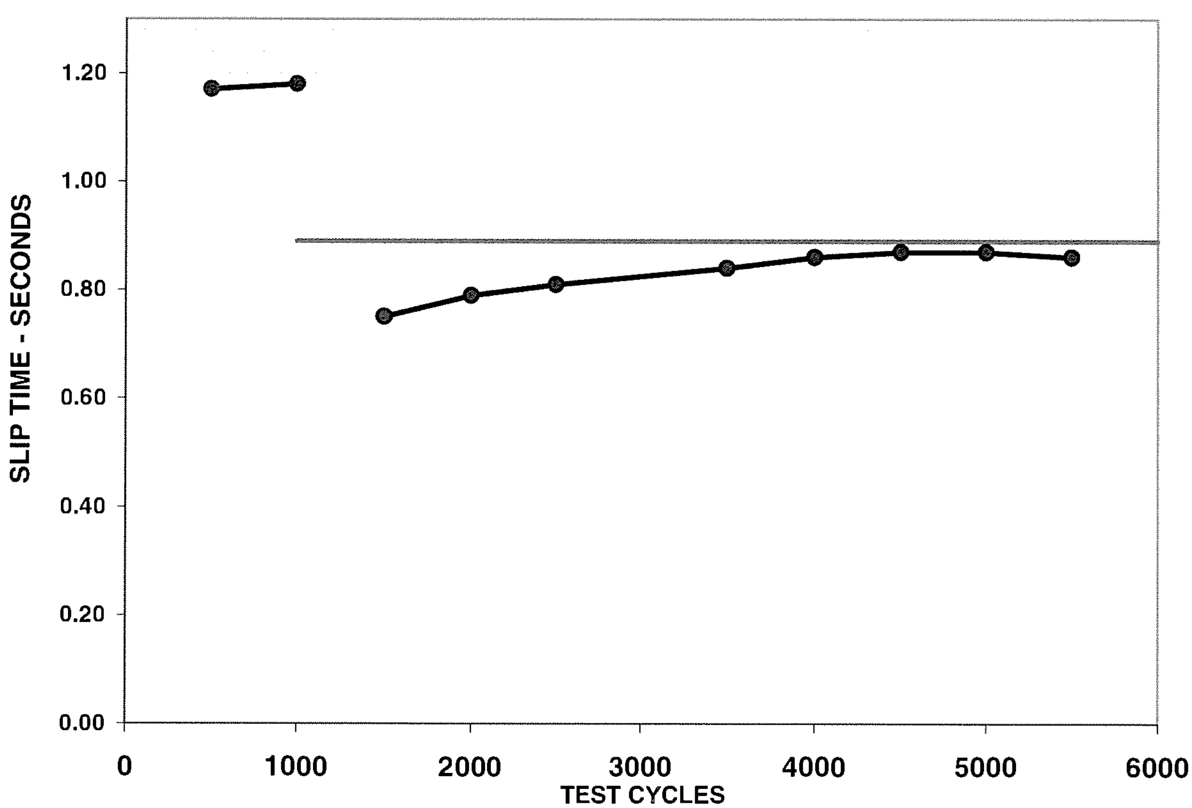
Pack ID#: 4667

ALLISON HEAVY-DUTY TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST

EOT Date: 10/14/2011
Test Number: C4-3-1341

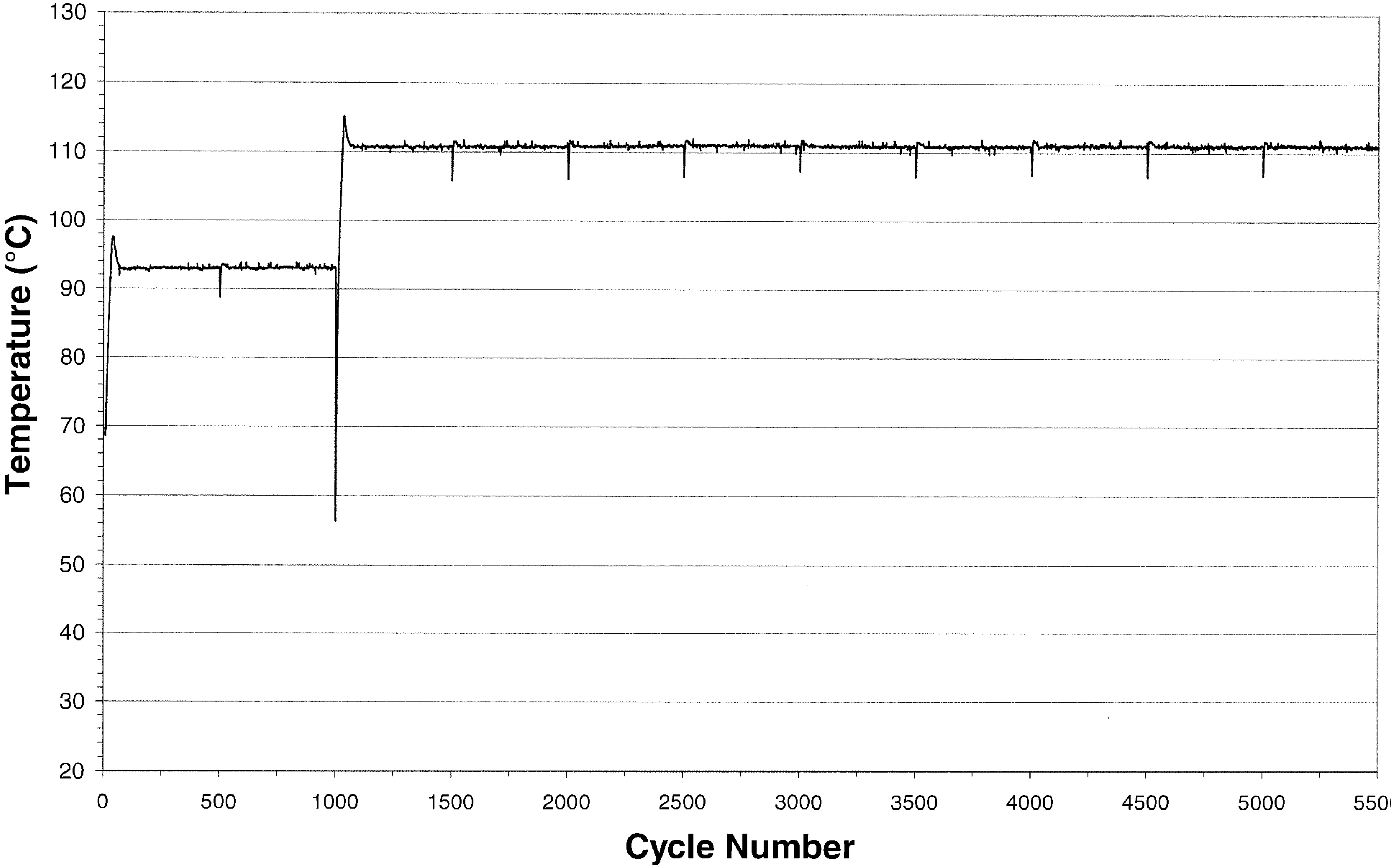
Fluid Code: LO268869
Plate Batch: LOT 44
Steel Batch: 10/9/2008





C4-3-1341 LO268869

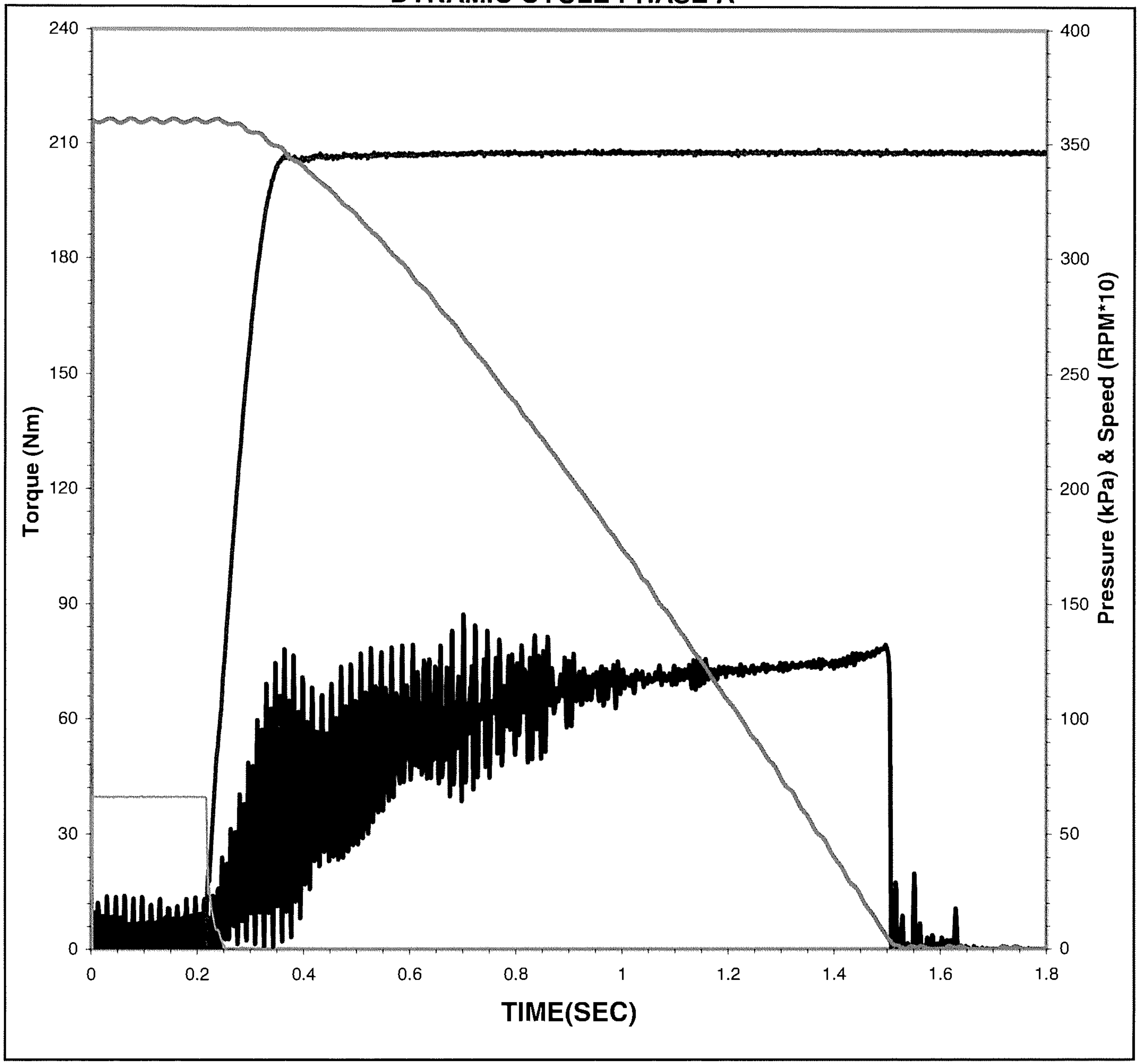
AVG: Phase A = 92.7 °C, Phase B = 110.8 °C



DYNAMIC TRACES

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/13/2011
Time of Test:	15:15:40
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	10
Temperature:	71.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.289 Sec

Torque

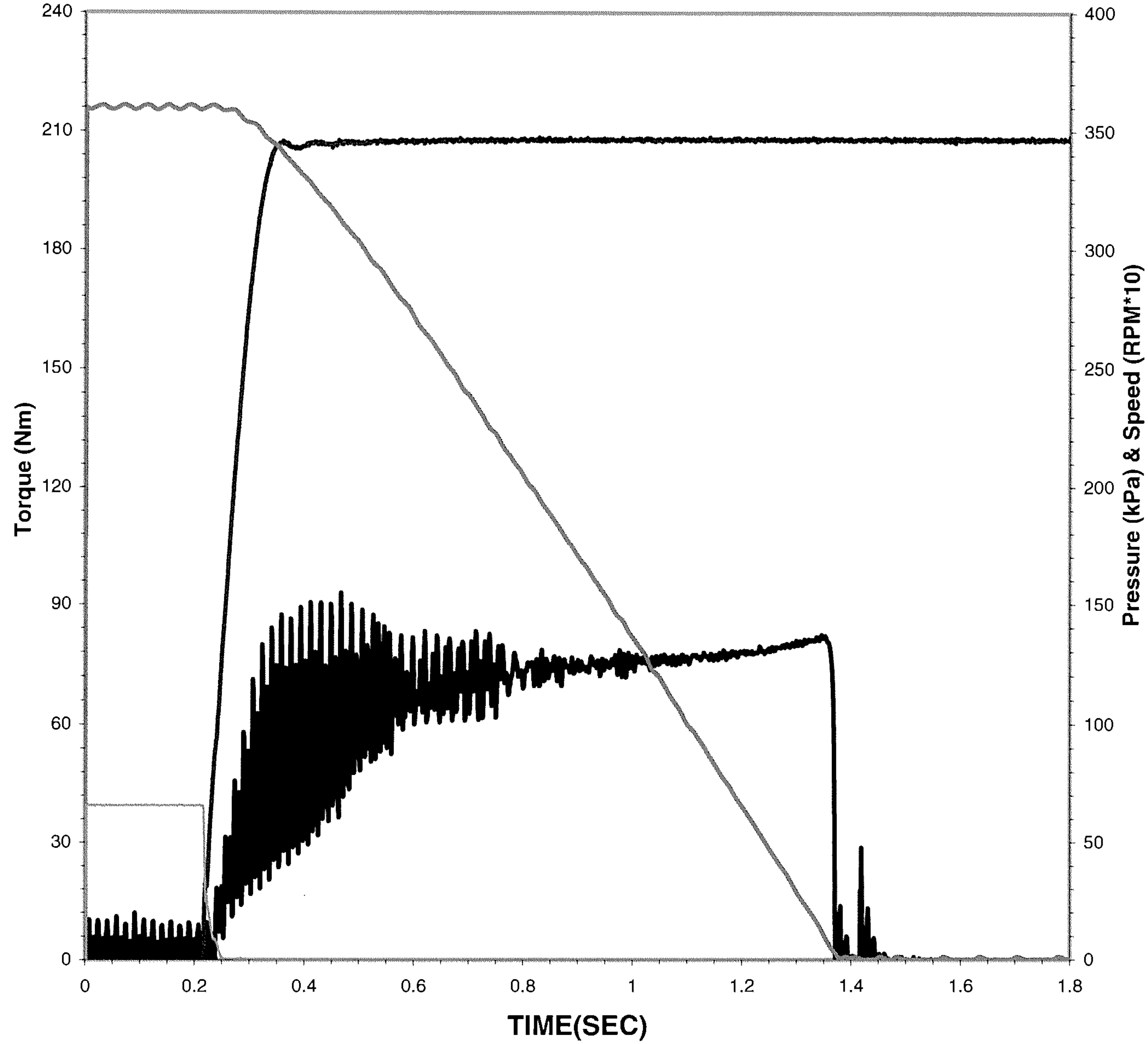
0.2 Sec Dyn:	44 N*m
Midpoint Dyn:	67 N*m
LwSpd Dynamic:	75 N*m

Coefficient of Friction

.2 Sec Dyn:	0.073
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 10/13/2011

Time of Test: 17:18:06

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 499

Temperature: 92.8 °C
(93.3 ± 3.0 °C)

Apply Pressure: 347 kPa
(345 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 14.3 KJ
(14.50 ± 0.40 KJ)

Engage Time: 1.152 Sec

Torque

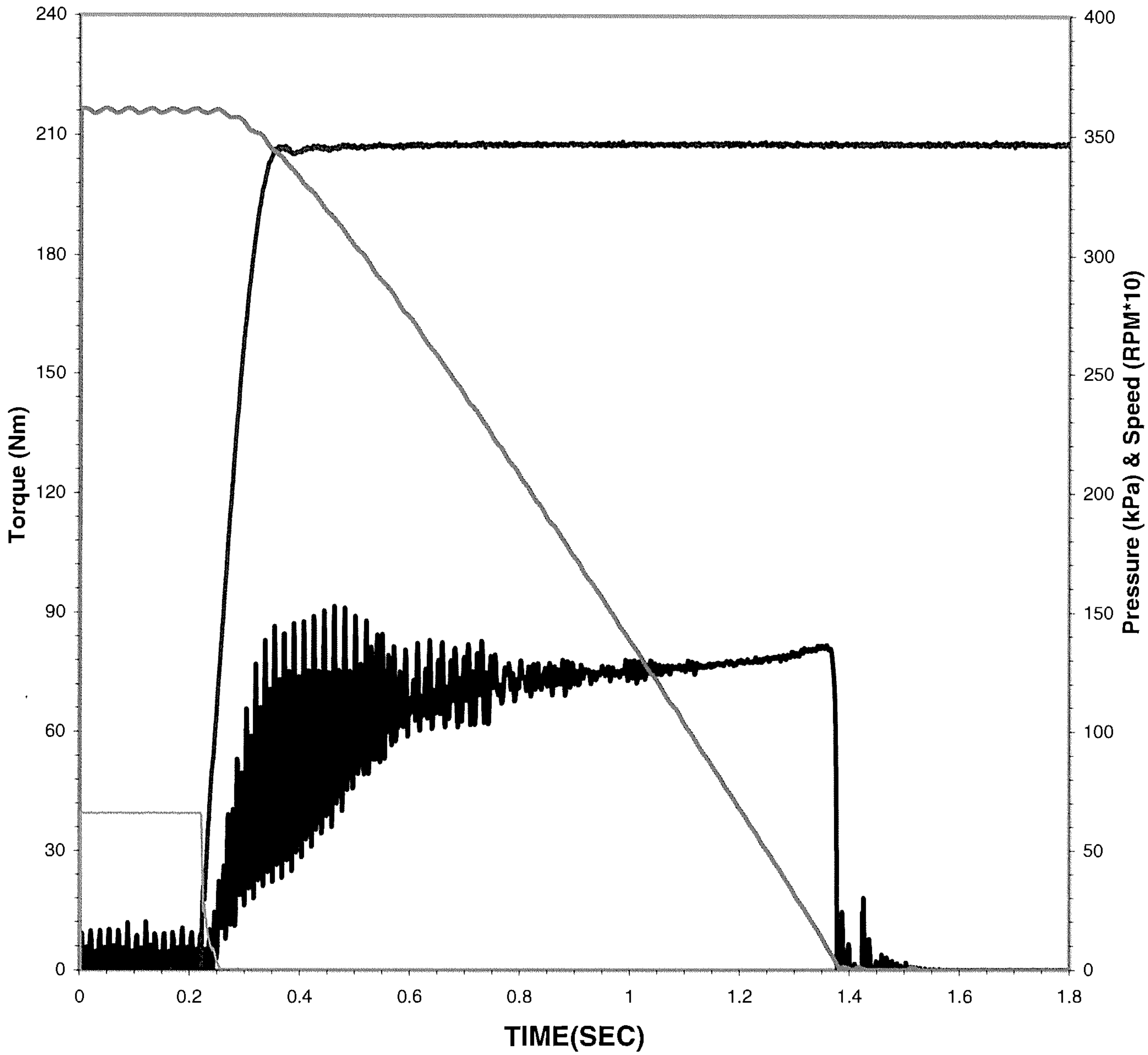
0.2 Sec Dyn: 57 N*m
Midpoint Dyn: 74 N*m
LwSpd Dynamic: 75 N*m

Coefficient of Friction

.2 Sec Dyn: 0.095
Midpoint Dyn: 0.122
LwSpd Dynamic: 0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/13/2011
Time of Test:	17:18:21
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	500
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.154 Sec

Torque

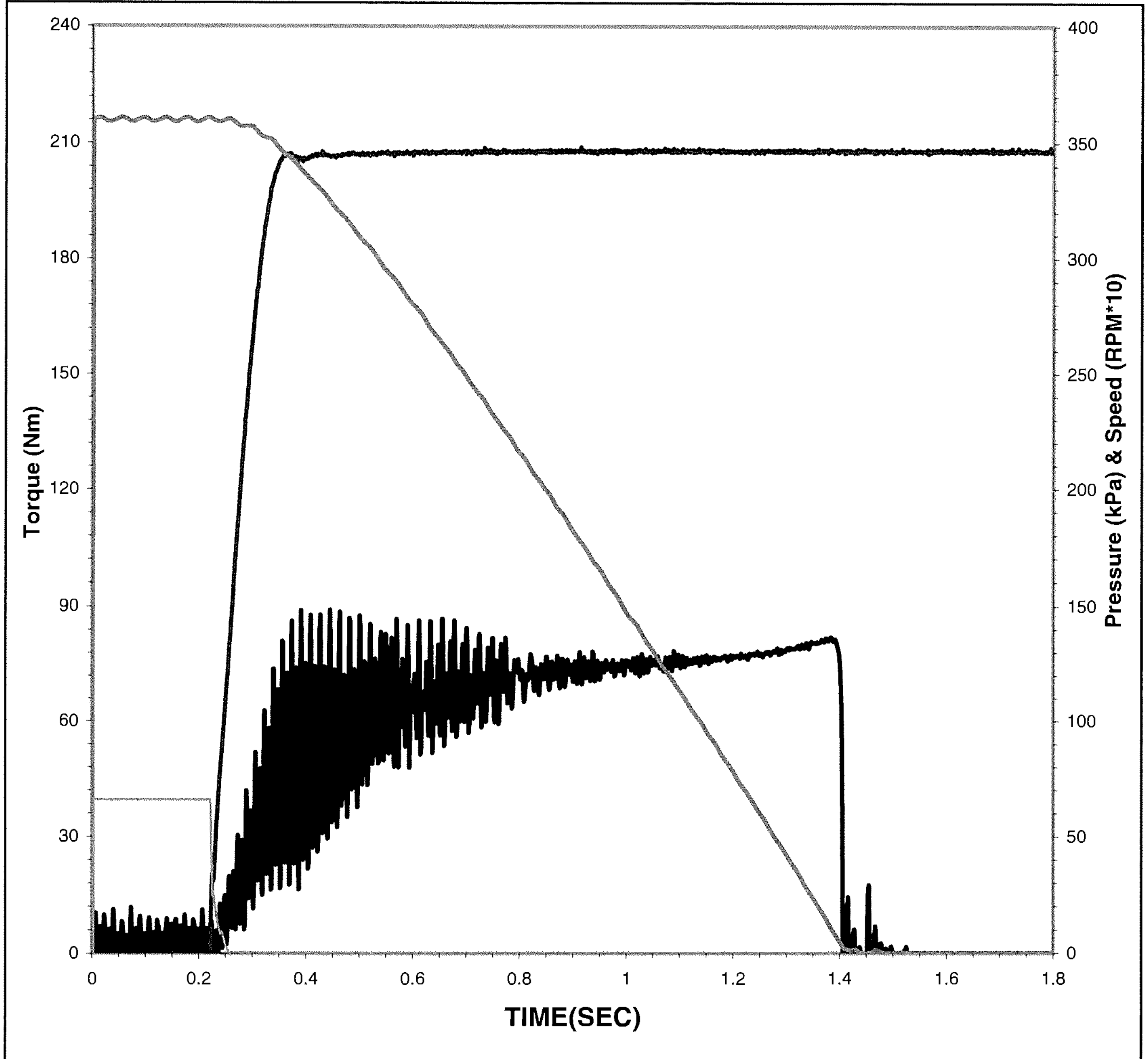
0.2 Sec Dyn:	57 N*m
Midpoint Dyn:	74 N*m
LwSpd Dynamic:	75 N*m

Coefficient of Friction

.2 Sec Dyn:	0.095
Midpoint Dyn:	0.122
LwSpd Dynamic:	0.124

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/13/2011
Time of Test:	17:18:48
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	501
Temperature:	88.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.183 Sec

Torque

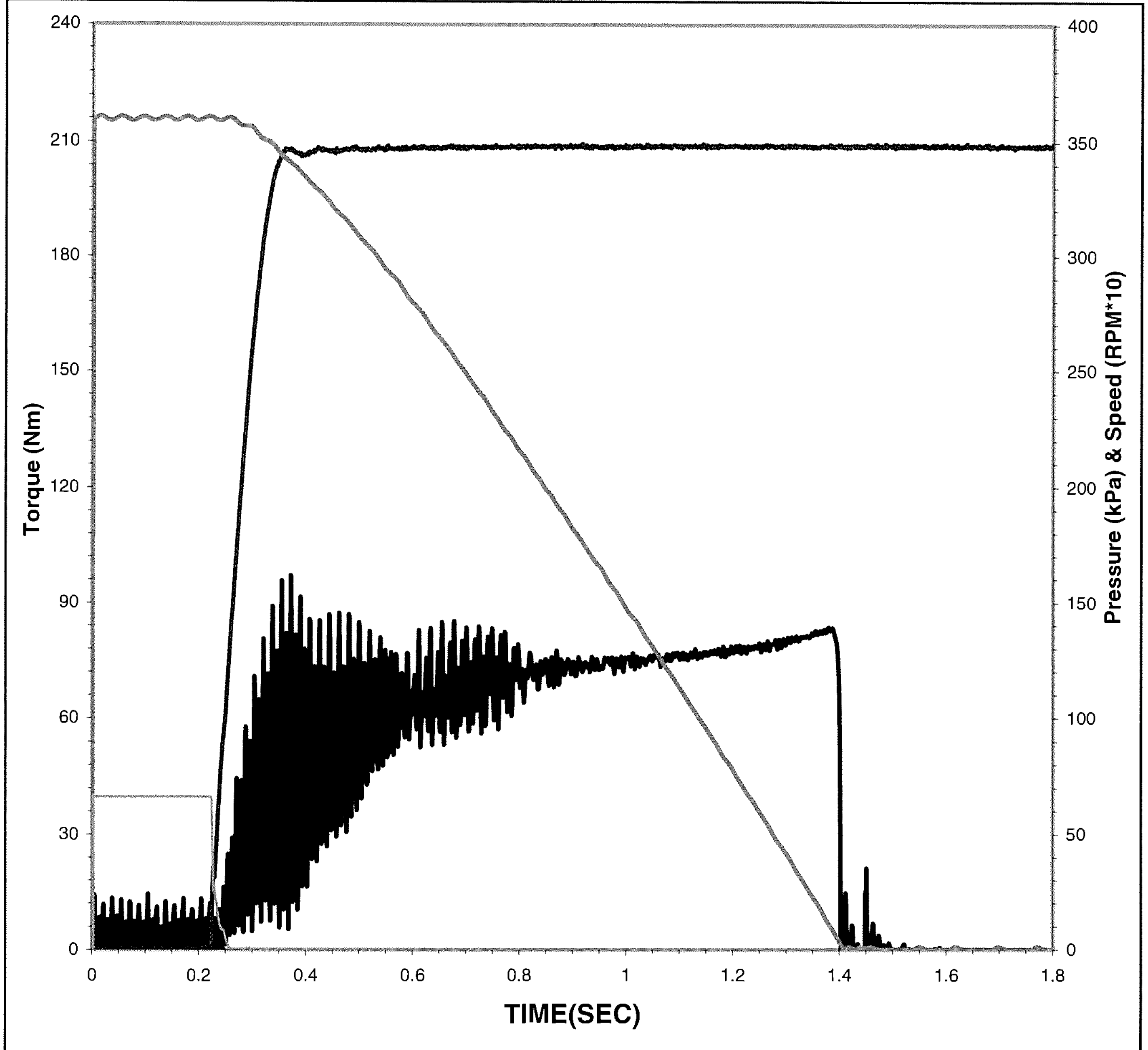
0.2 Sec Dyn:	56 N*m
Midpoint Dyn:	73 N*m
LwSpd Dynamic:	76 N*m

Coefficient of Friction

.2 Sec Dyn:	0.092
Midpoint Dyn:	0.121
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/13/2011
Time of Test:	19:23:03
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	998
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	348 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.177 Sec

Torque

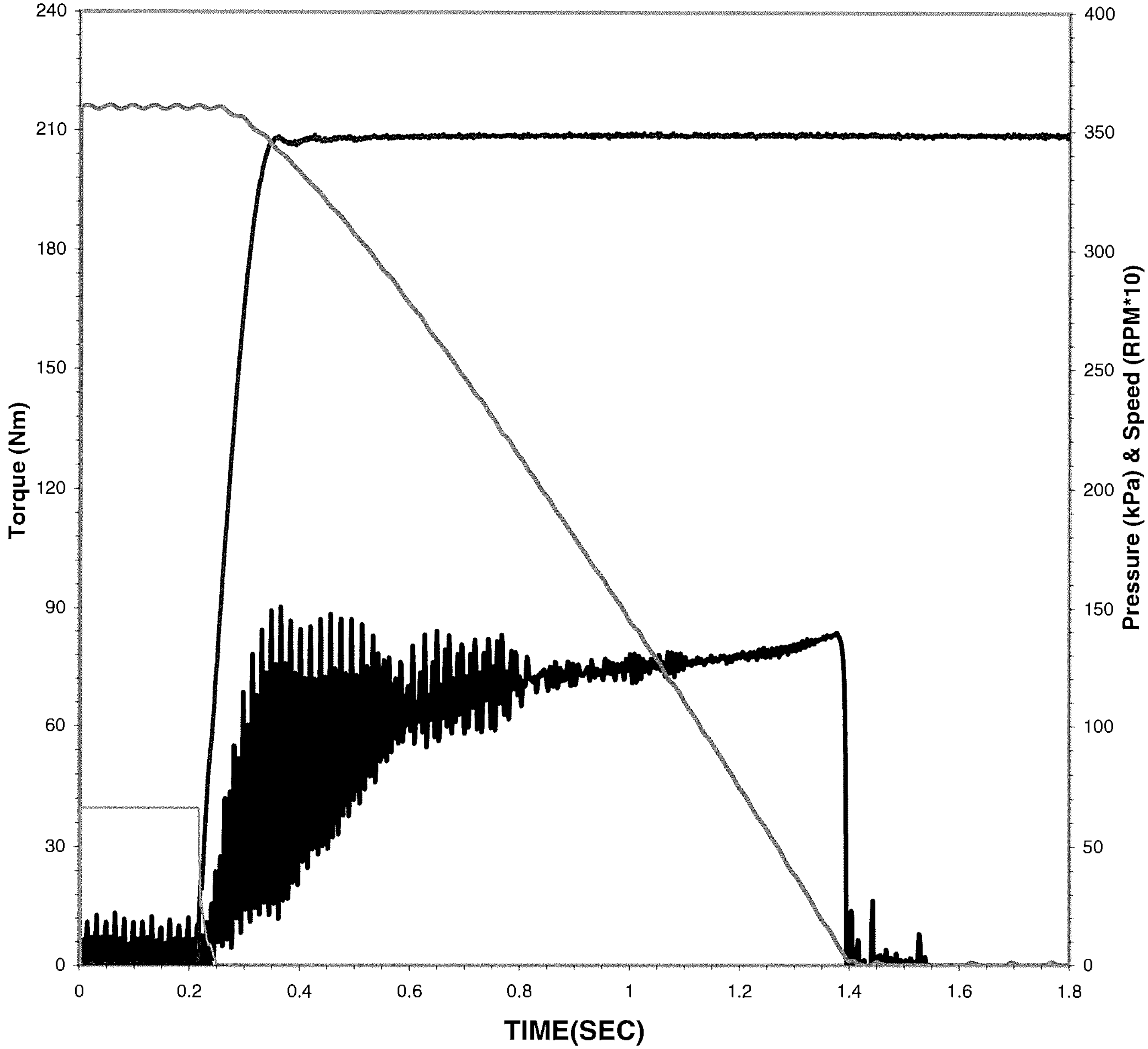
0.2 Sec Dyn:	52 N*m
Midpoint Dyn:	73 N*m
LwSpd Dynamic:	76 N*m

Coefficient of Friction

.2 Sec Dyn:	0.086
Midpoint Dyn:	0.121
LwSpd Dynamic:	0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/13/2011
Time of Test:	19:23:18
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	999
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	348 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.176 Sec

Torque

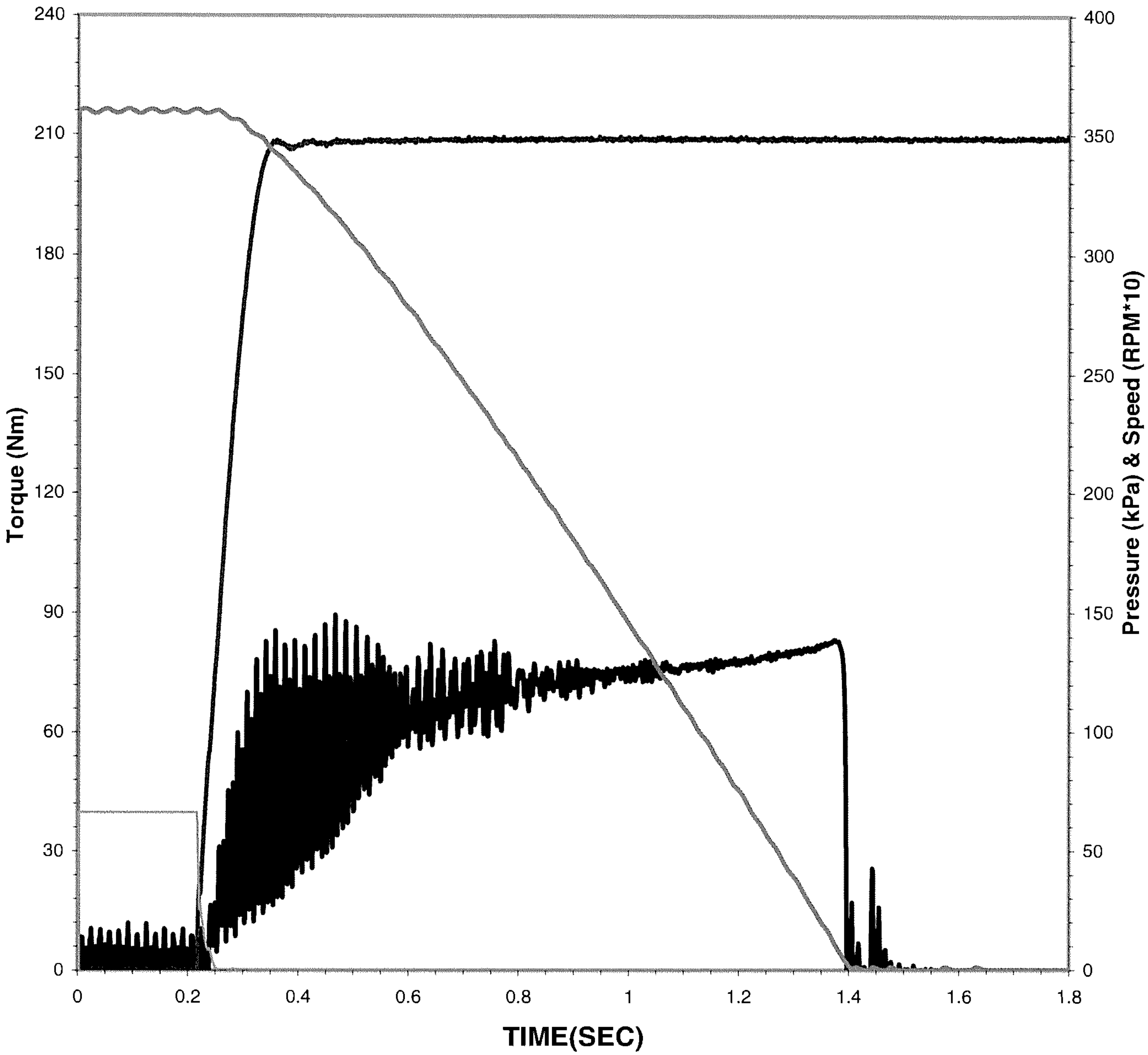
0.2 Sec Dyn:	52 N*m
Midpoint Dyn:	73 N*m
LwSpd Dynamic:	77 N*m

Coefficient of Friction

.2 Sec Dyn:	0.086
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/13/2011
Time of Test:	19:23:33
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	1000
Temperature:	93.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	348 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.178 Sec

Torque

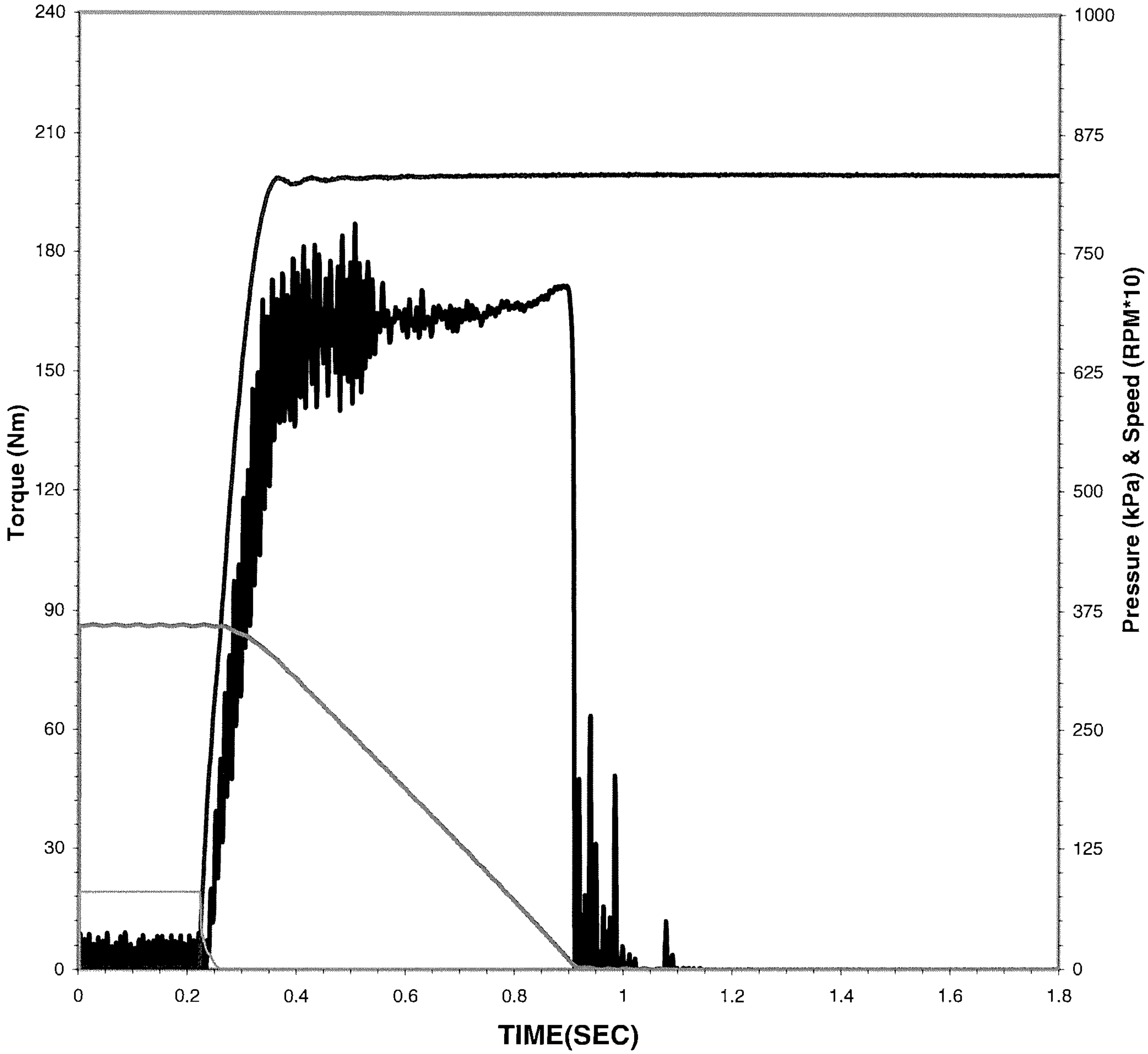
0.2 Sec Dyn:	52 N*m
Midpoint Dyn:	72 N*m
LwSpd Dynamic:	76 N*m

Coefficient of Friction

.2 Sec Dyn:	0.086
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/13/2011
Time of Test:	20:17:13
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	1010
Temperature:	89.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.688 Sec

Torque

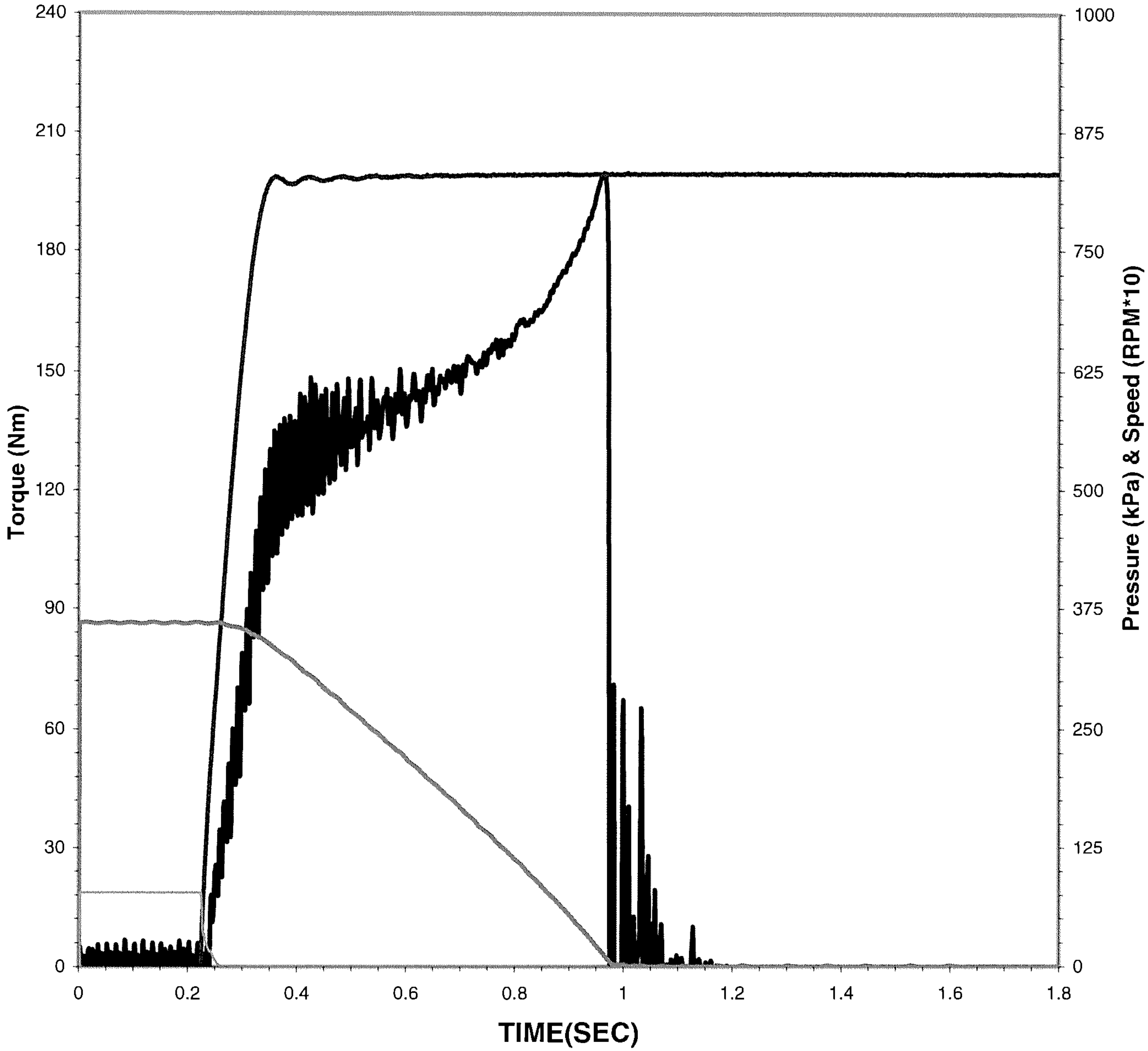
0.2 Sec Dyn:	161 N*m
Midpoint Dyn:	163 N*m
LwSpd Dynamic:	159 N*m

Coefficient of Friction

.2 Sec Dyn:	0.112
Midpoint Dyn:	0.113
LwSpd Dynamic:	0.110

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/13/2011
Time of Test:	22:19:29
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	1499
Temperature:	110.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.75 Sec

Torque

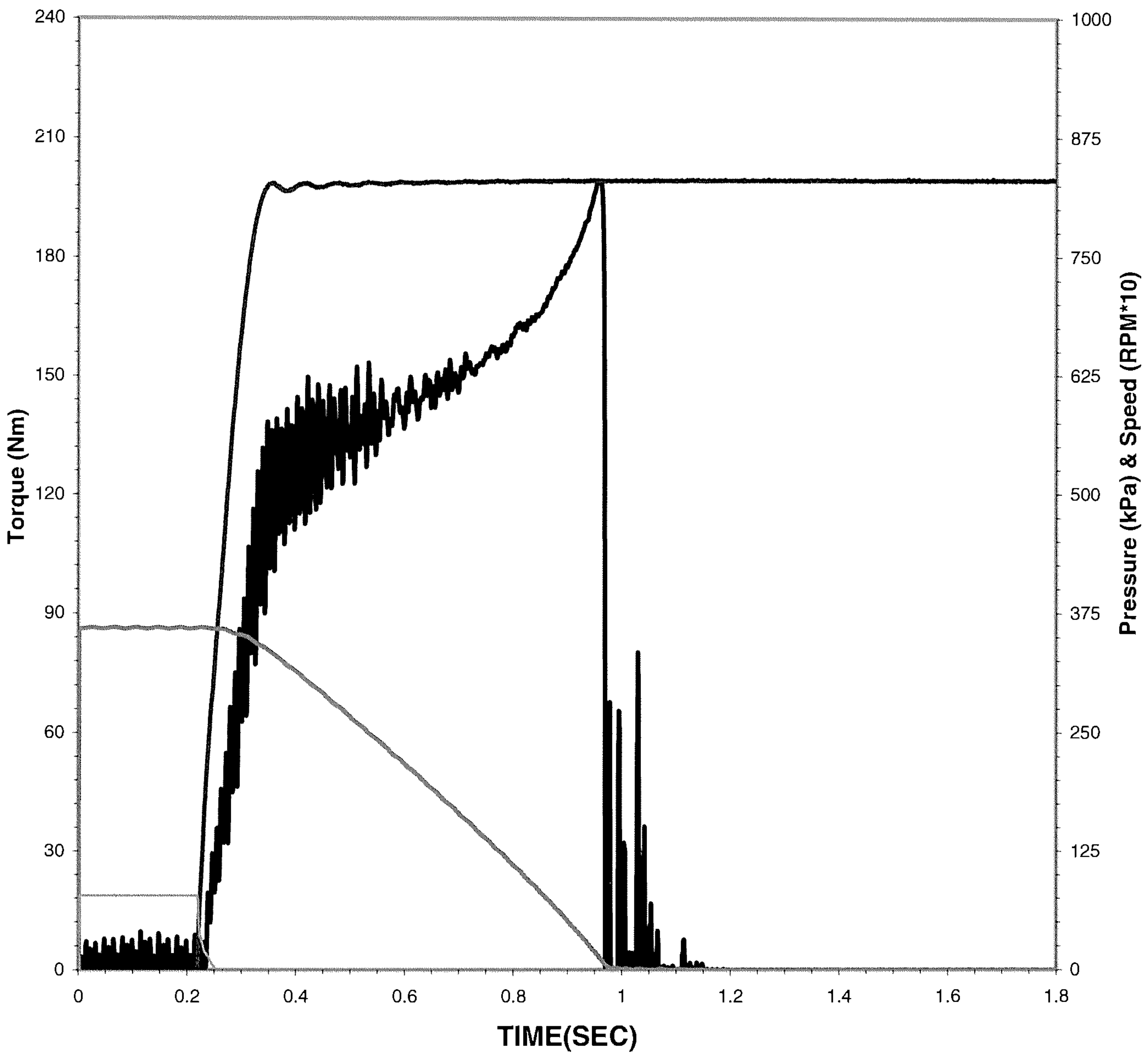
0.2 Sec Dyn:	131 N*m
Midpoint Dyn:	143 N*m
LwSpd Dynamic:	194 N*m

Coefficient of Friction

.2 Sec Dyn:	0.090
Midpoint Dyn:	0.099
LwSpd Dynamic:	0.134

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 10/13/2011

Time of Test: 22:19:44

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 1500

Temperature: 110.8 °C
(112.7 ± 3.0 °C)

Apply Pressure: 829 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.75 Sec

Torque

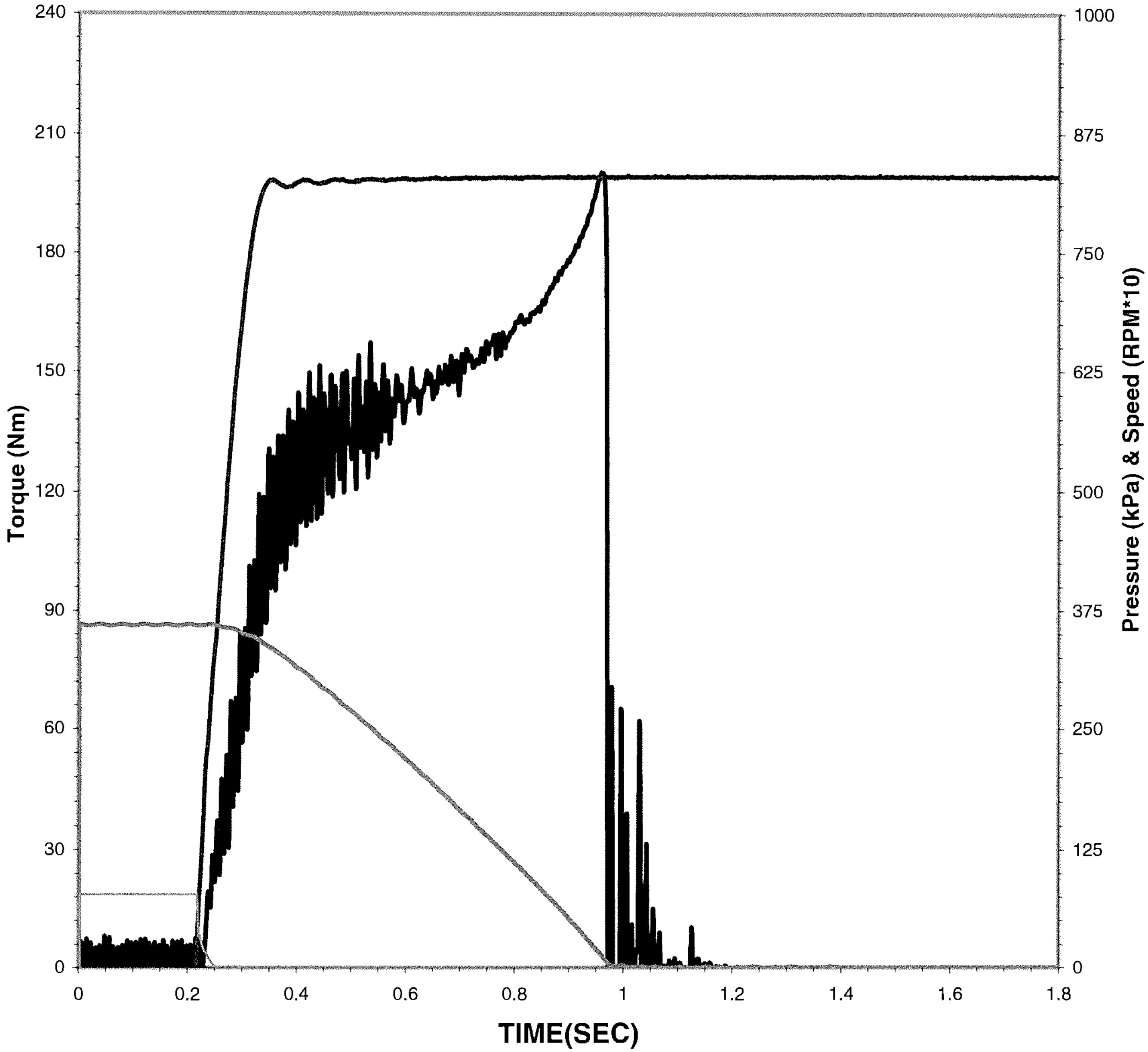
0.2 Sec Dyn:	130 N*m
Midpoint Dyn:	143 N*m
LwSpd Dynamic:	192 N*m

Coefficient of Friction

.2 Sec Dyn:	0.090
Midpoint Dyn:	0.099
LwSpd Dynamic:	0.132

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/13/2011
Time of Test:	22:20:10
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	1501
Temperature:	105.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.755 Sec

Torque

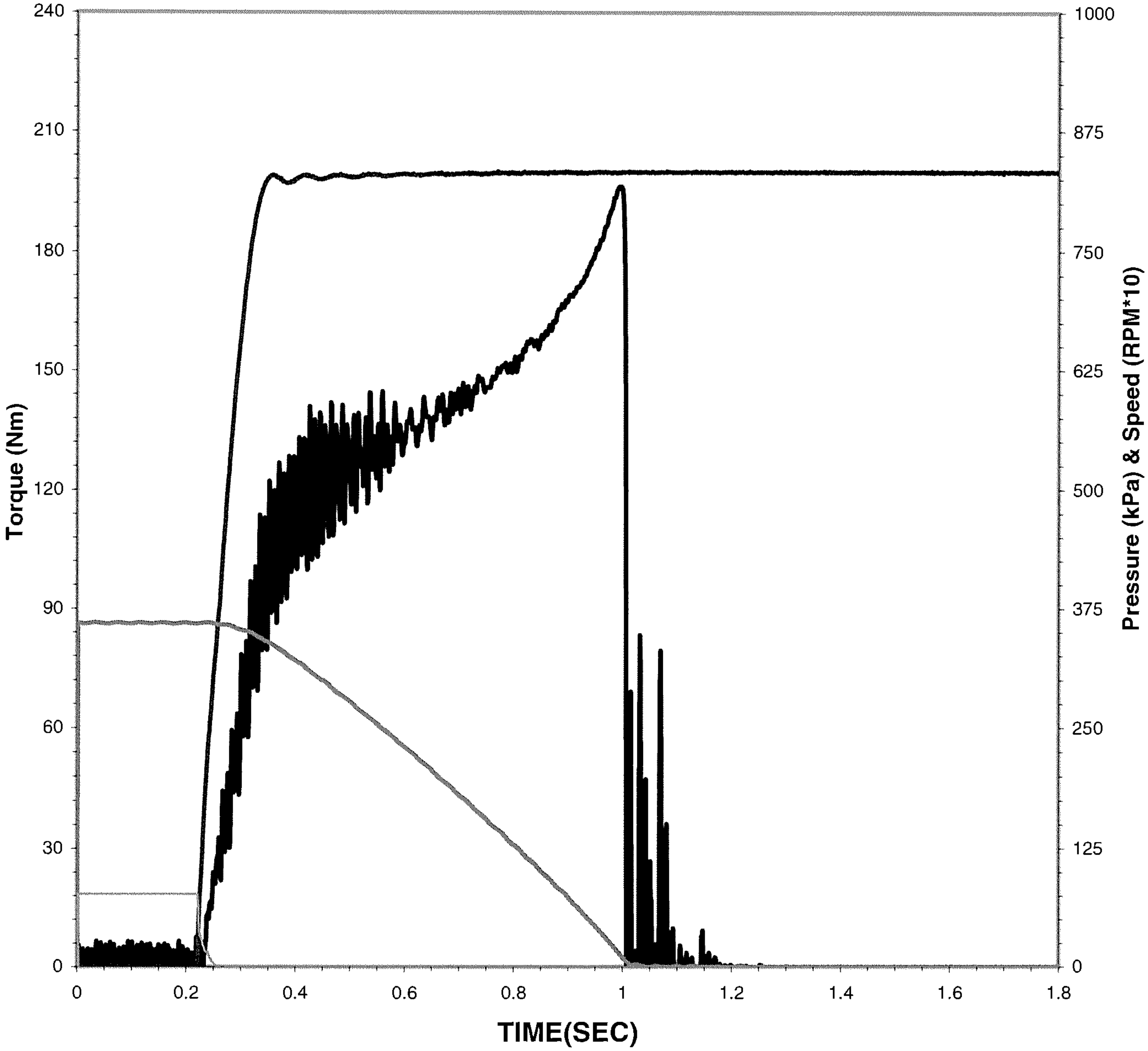
0.2 Sec Dyn:	131 N*m
Midpoint Dyn:	143 N*m
LwSpd Dynamic:	190 N*m

Coefficient of Friction

.2 Sec Dyn:	0.091
Midpoint Dyn:	0.099
LwSpd Dynamic:	0.131

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	0:24:40
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	1999
Temperature:	110.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.786 Sec

Torque

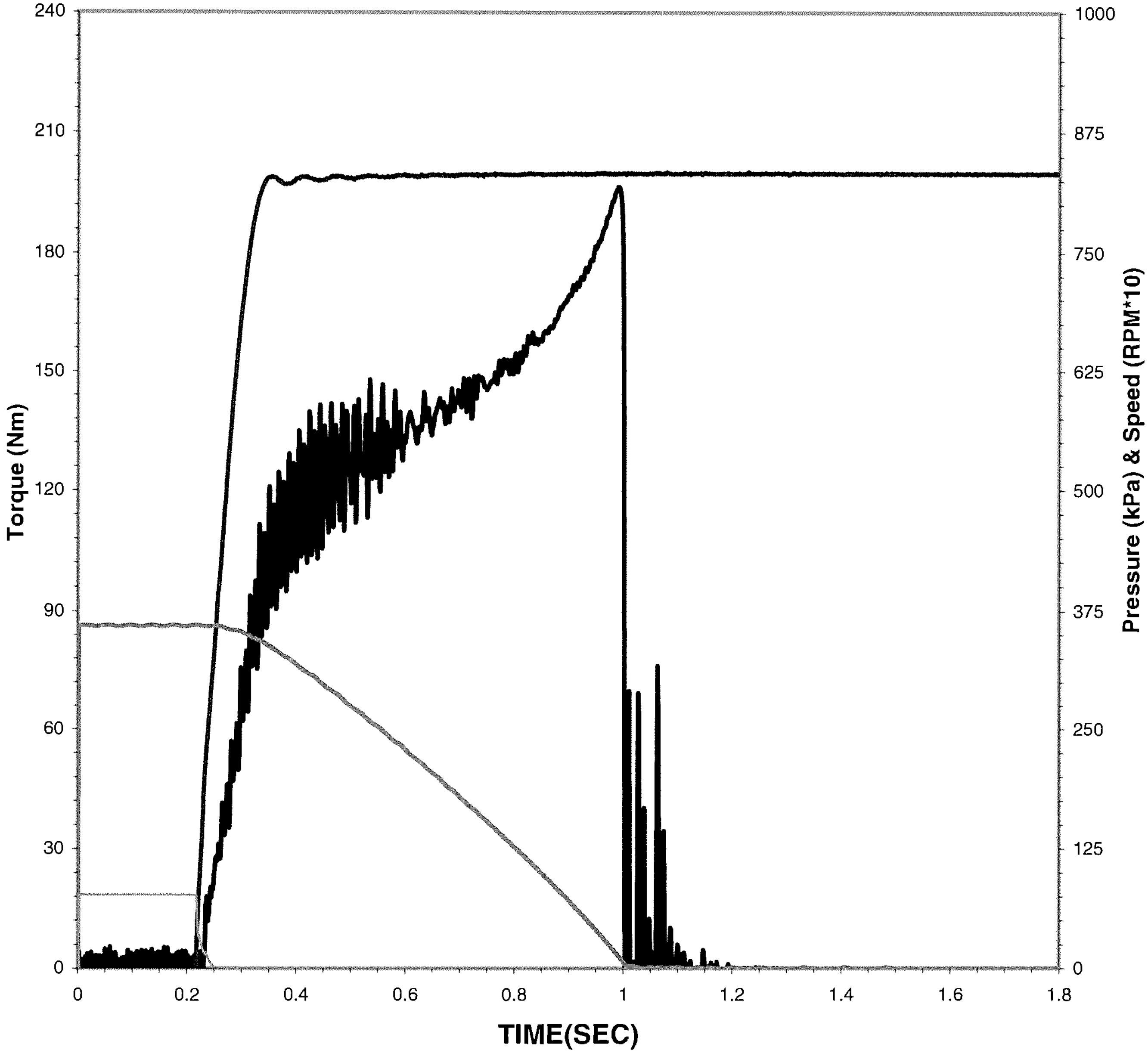
0.2 Sec Dyn:	121 N*m
Midpoint Dyn:	136 N*m
LwSpd Dynamic:	189 N*m

Coefficient of Friction

.2 Sec Dyn:	0.084
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.131

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	0:24:55
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	2000
Temperature:	110.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.786 Sec

Torque

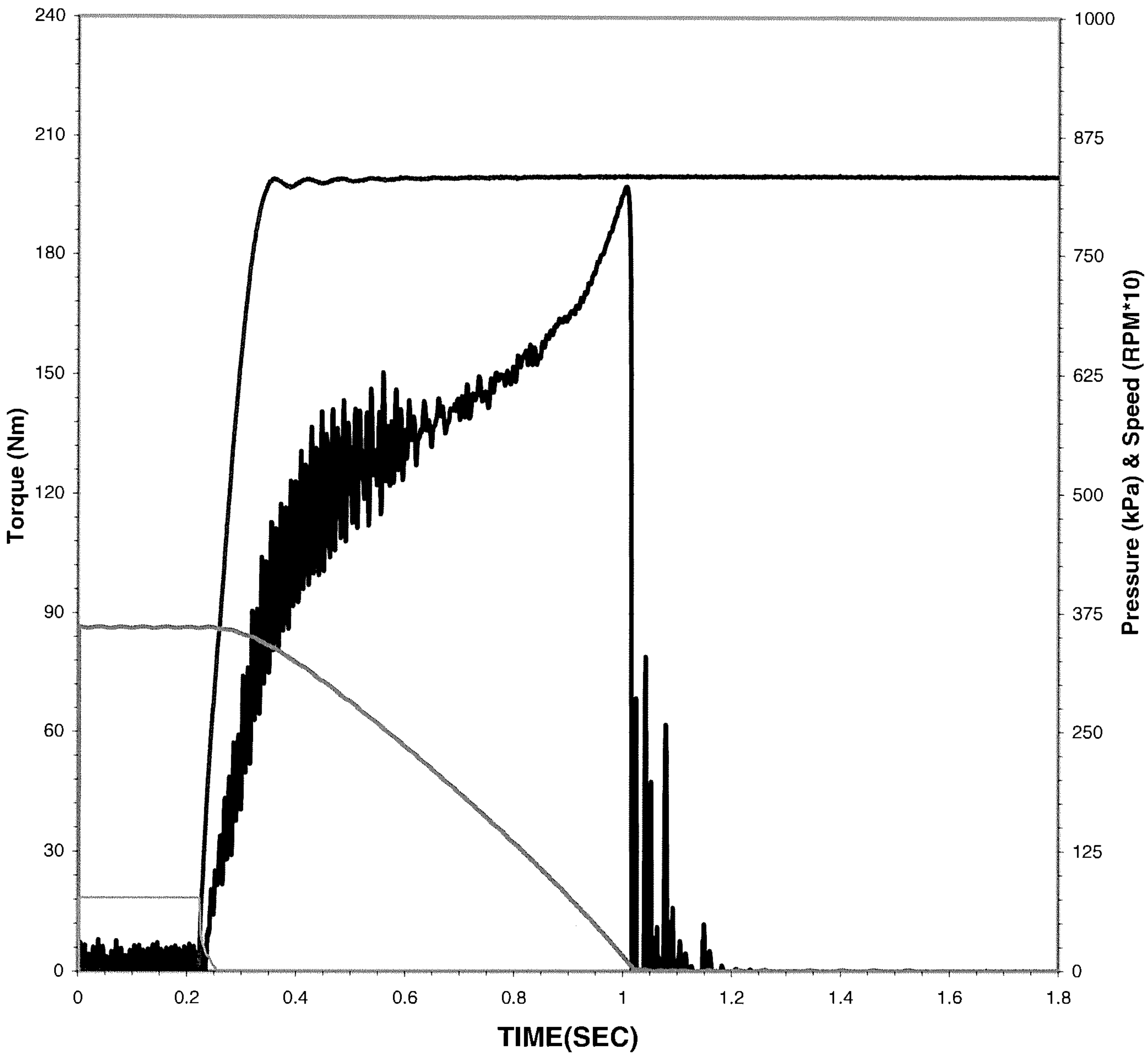
0.2 Sec Dyn:	121 N*m
Midpoint Dyn:	136 N*m
LwSpd Dynamic:	189 N*m

Coefficient of Friction

.2 Sec Dyn:	0.084
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.131

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	0:25:22
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	2001
Temperature:	106.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.794 Sec

Torque

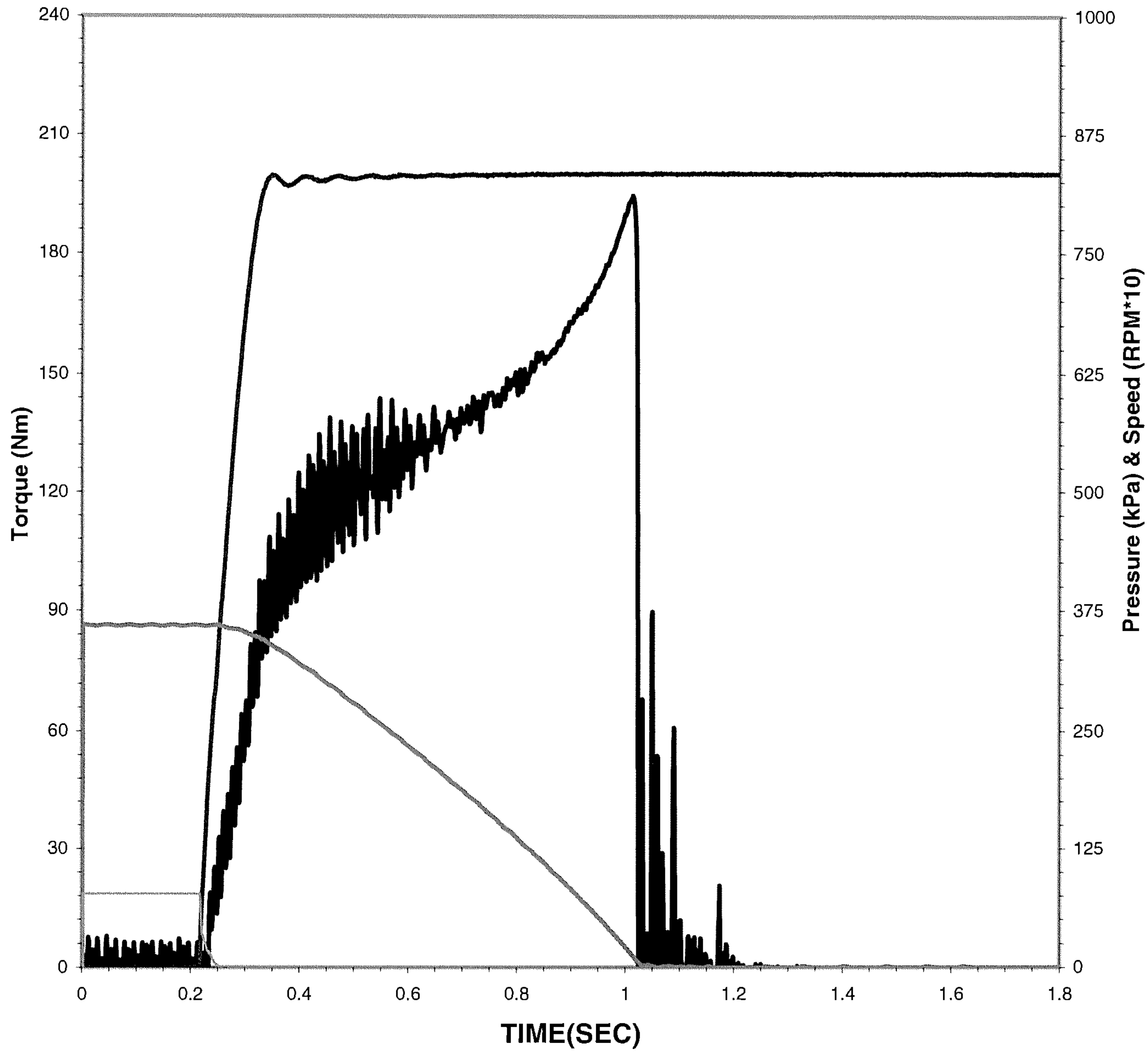
0.2 Sec Dyn:	117 N*m
Midpoint Dyn:	136 N*m
LwSpd Dynamic:	191 N*m

Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.132

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	2:29:52
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	2499
Temperature:	111.0 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	830 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.807 Sec

Torque

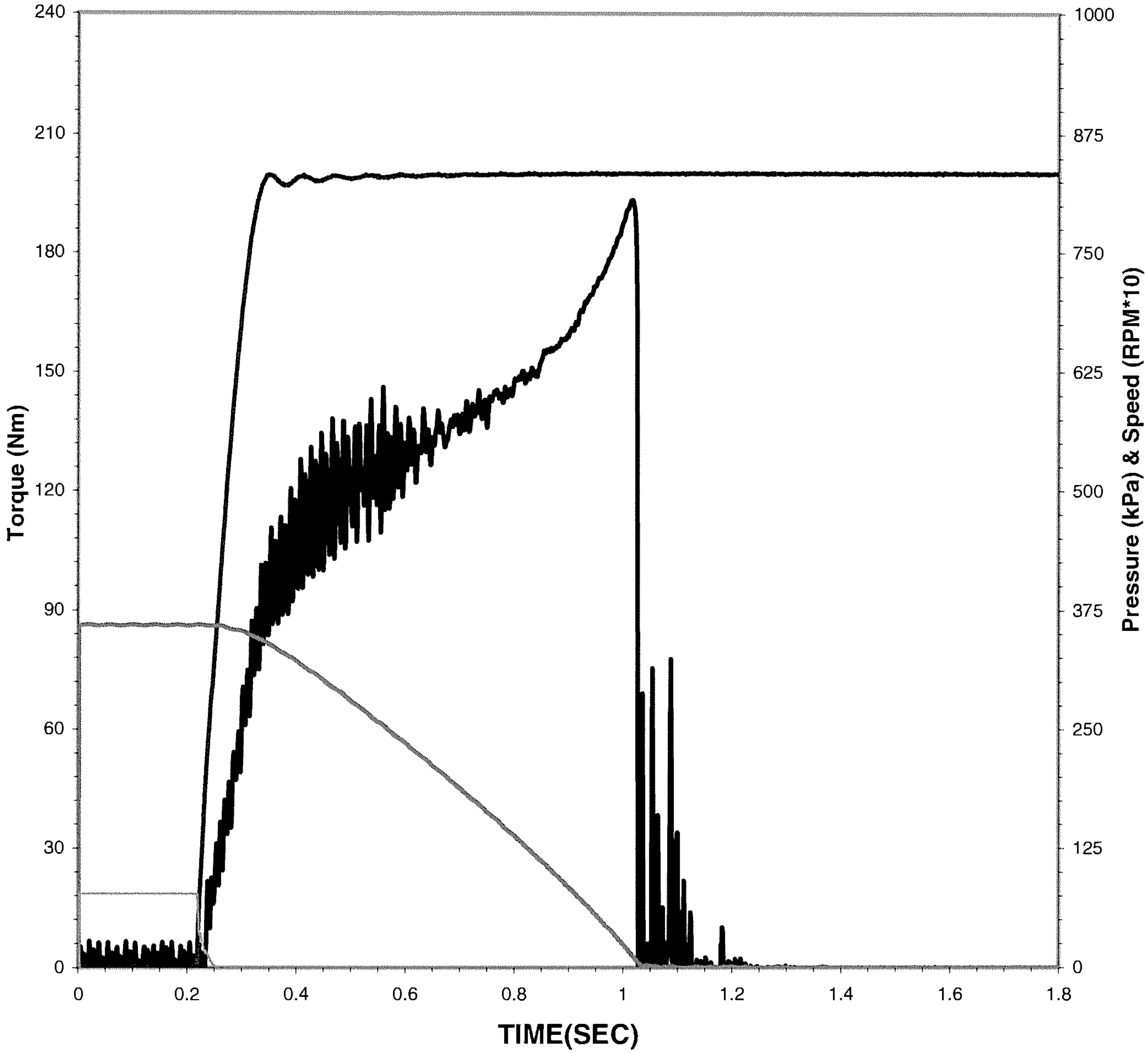
0.2 Sec Dyn:	113 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	186 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	2:30:07
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	2500
Temperature:	110.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.809 Sec

Torque

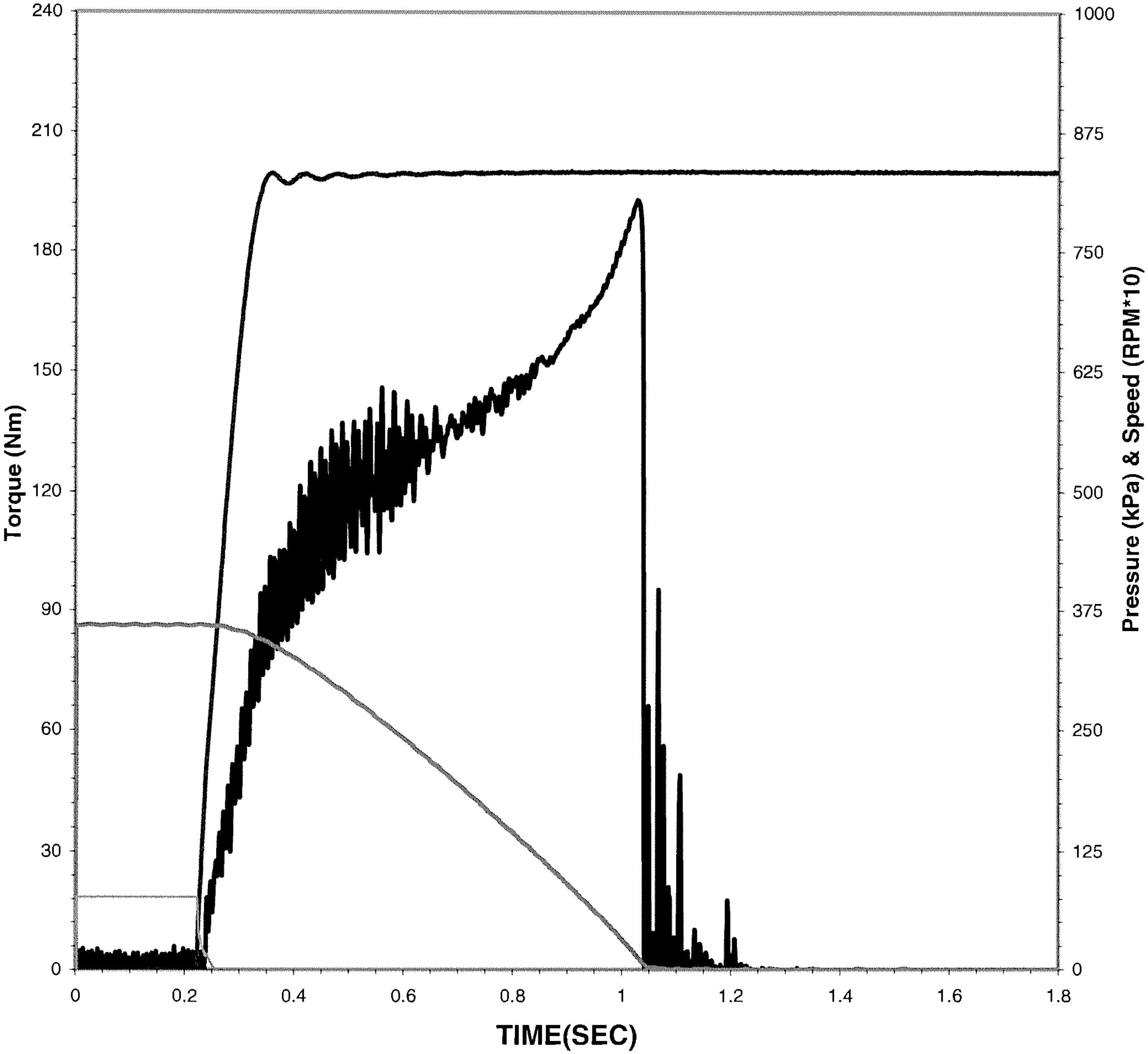
0.2 Sec Dyn:	113 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	186 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 10/14/2011

Time of Test: 2:30:34

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 2501

Temperature: 106.4 °C
(112.7 ± 3.0 °C)

Apply Pressure: 830 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.819 Sec

Torque

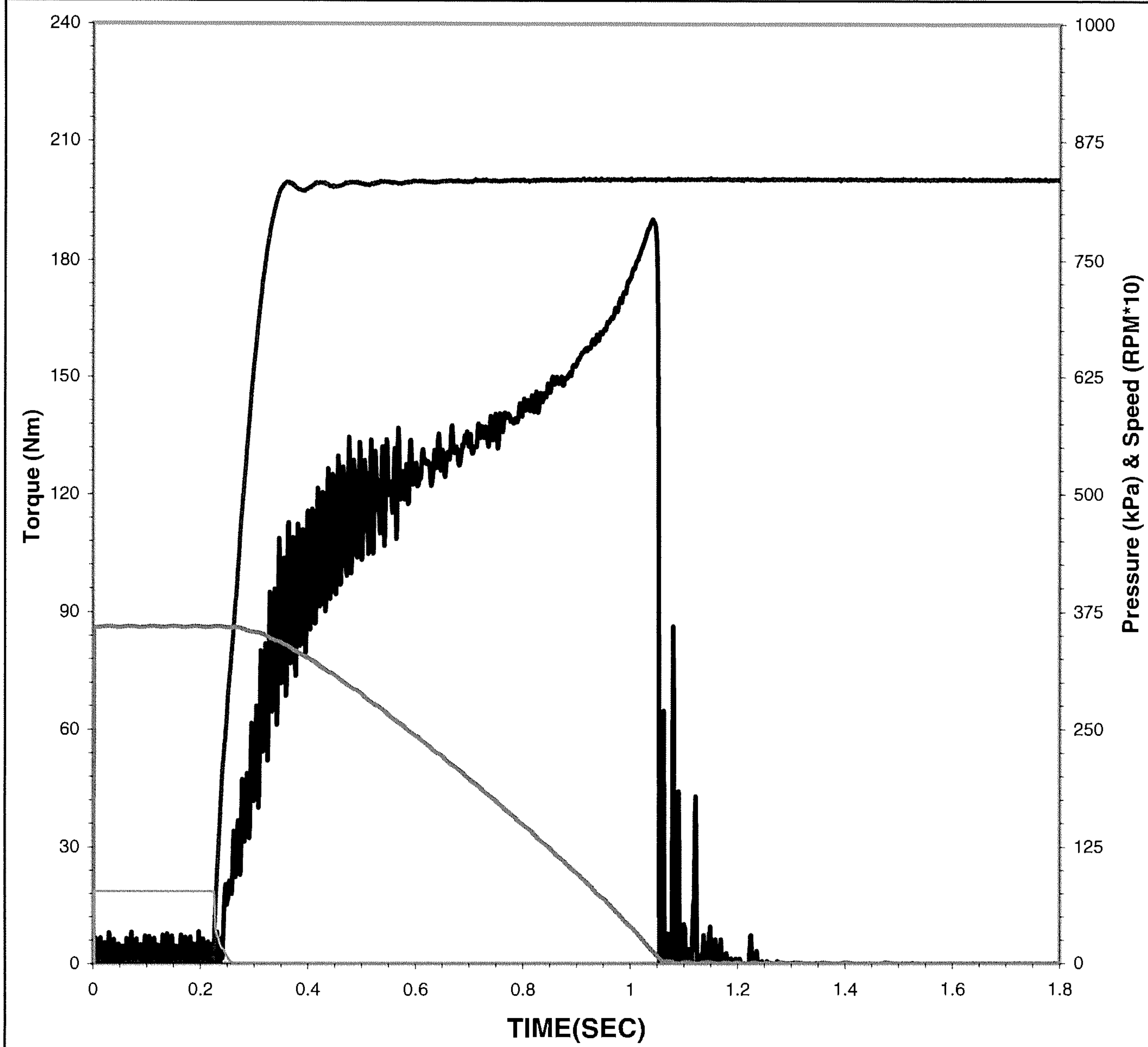
0.2 Sec Dyn:	109 N*m
Midpoint Dyn:	131 N*m
LwSpd Dynamic:	186 N*m

Coefficient of Friction

.2 Sec Dyn:	0.076
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 10/14/2011

Time of Test: 4:35:04

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 2999

Temperature: 110.9 °C
(112.7 ± 3.0 °C)

Apply Pressure: 831 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.829 Sec

Torque

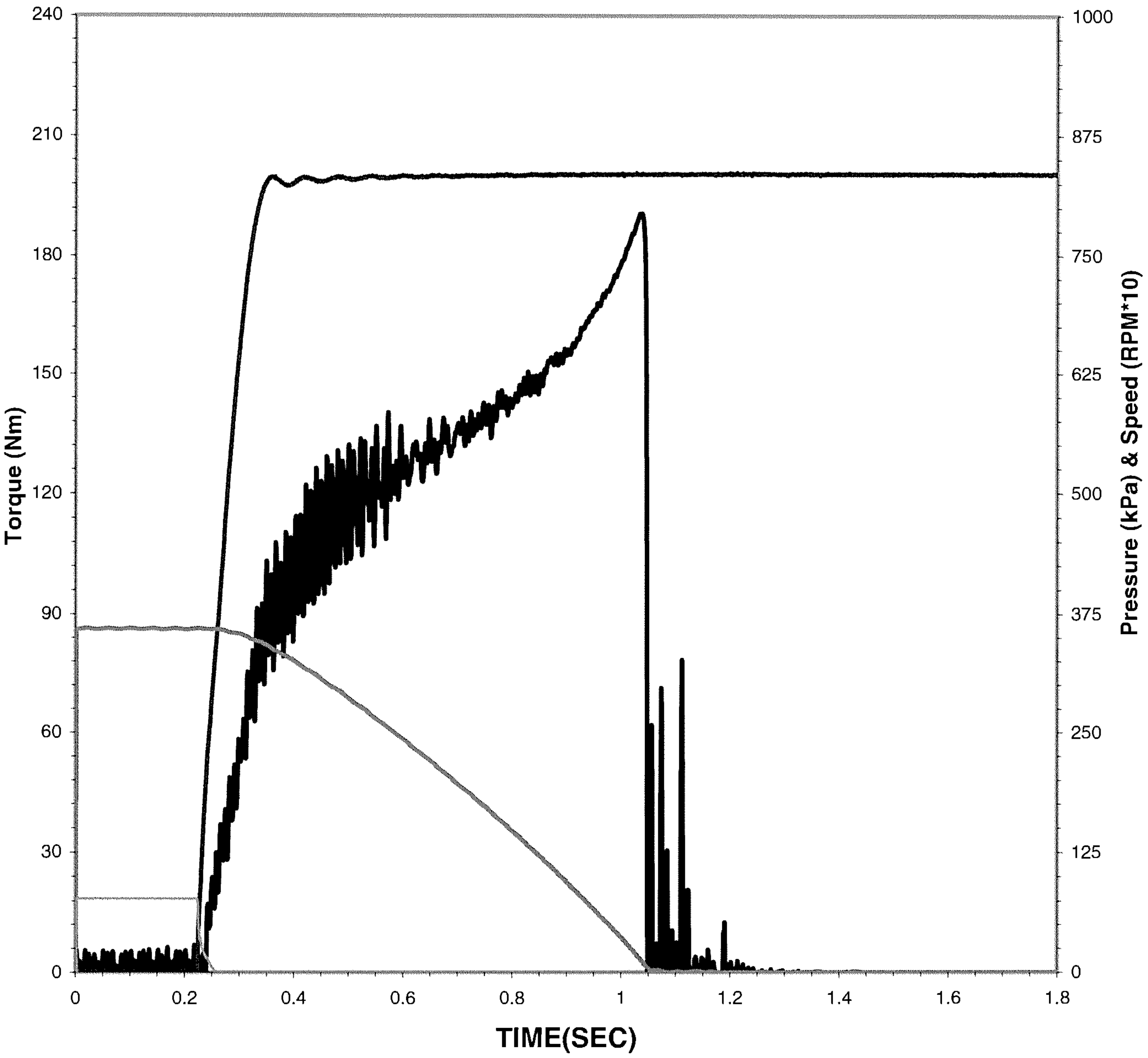
0.2 Sec Dyn: 106 N*m
Midpoint Dyn: 129 N*m
LwSpd Dynamic: 182 N*m

Coefficient of Friction

.2 Sec Dyn: 0.073
Midpoint Dyn: 0.089
LwSpd Dynamic: 0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	4:35:19
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	3000
Temperature:	110.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.825 Sec

Torque

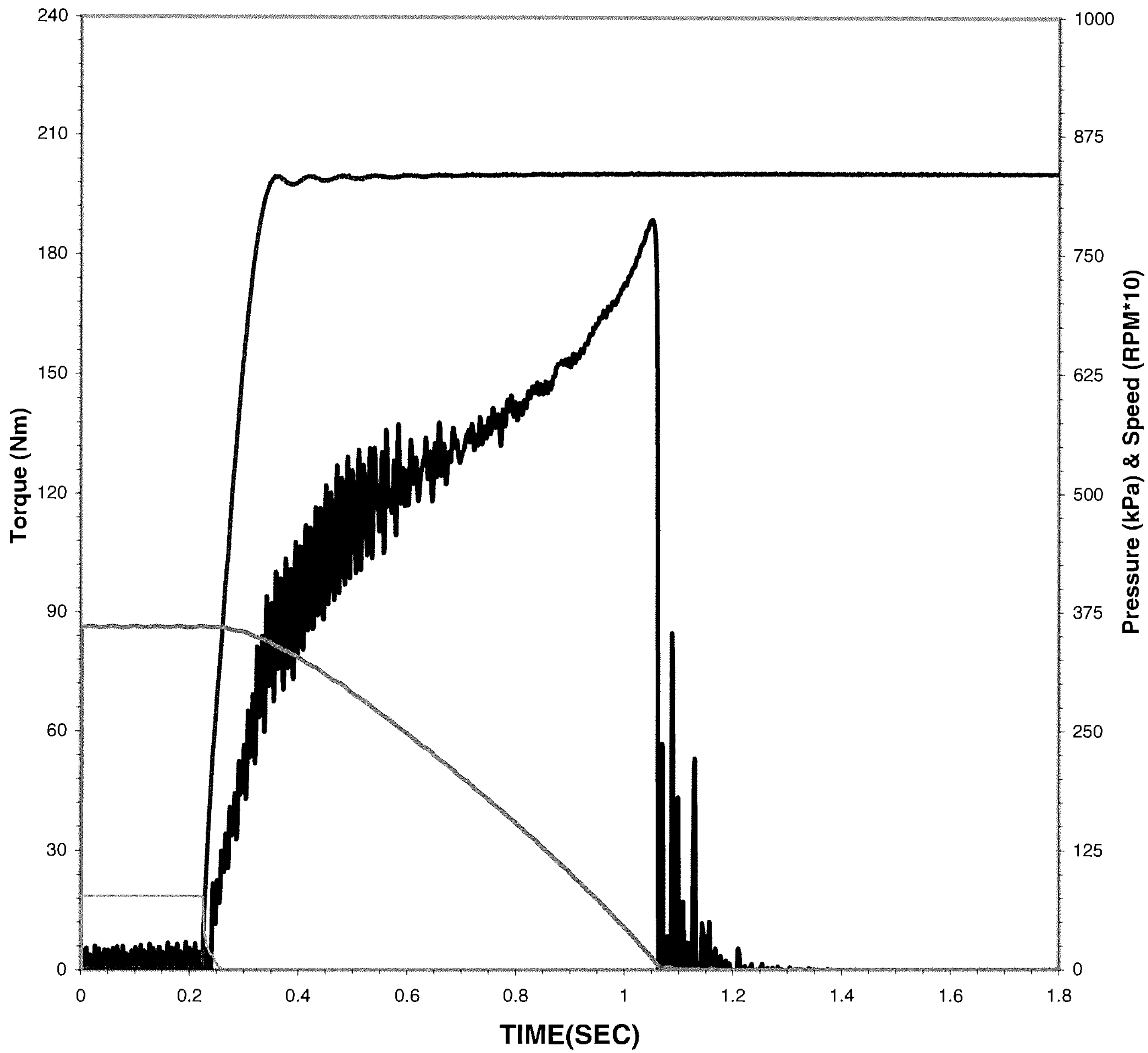
0.2 Sec Dyn:	107 N*m
Midpoint Dyn:	130 N*m
LwSpd Dynamic:	179 N*m

Coefficient of Friction

.2 Sec Dyn:	0.074
Midpoint Dyn:	0.090
LwSpd Dynamic:	0.124

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 10/14/2011

Time of Test: 4:35:46

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 3001

Temperature: 107.2 °C
(112.7 ± 3.0 °C)

Apply Pressure: 831 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.838 Sec

Torque

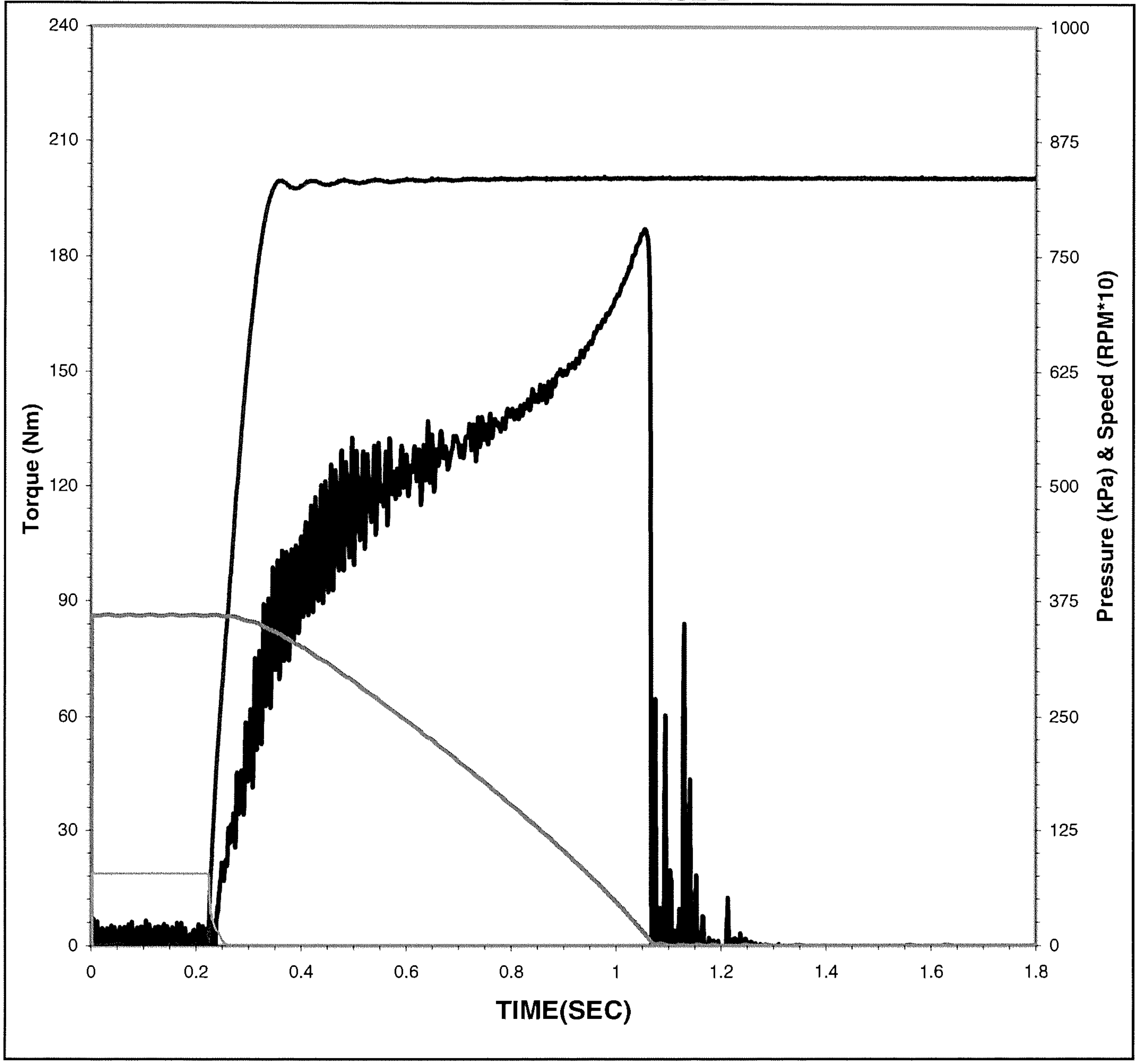
0.2 Sec Dyn:	102 N*m
Midpoint Dyn:	128 N*m
LwSpd Dynamic:	177 N*m

Coefficient of Friction

.2 Sec Dyn:	0.070
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.123

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	6:40:16
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	3499
Temperature:	110.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.843 Sec

Torque

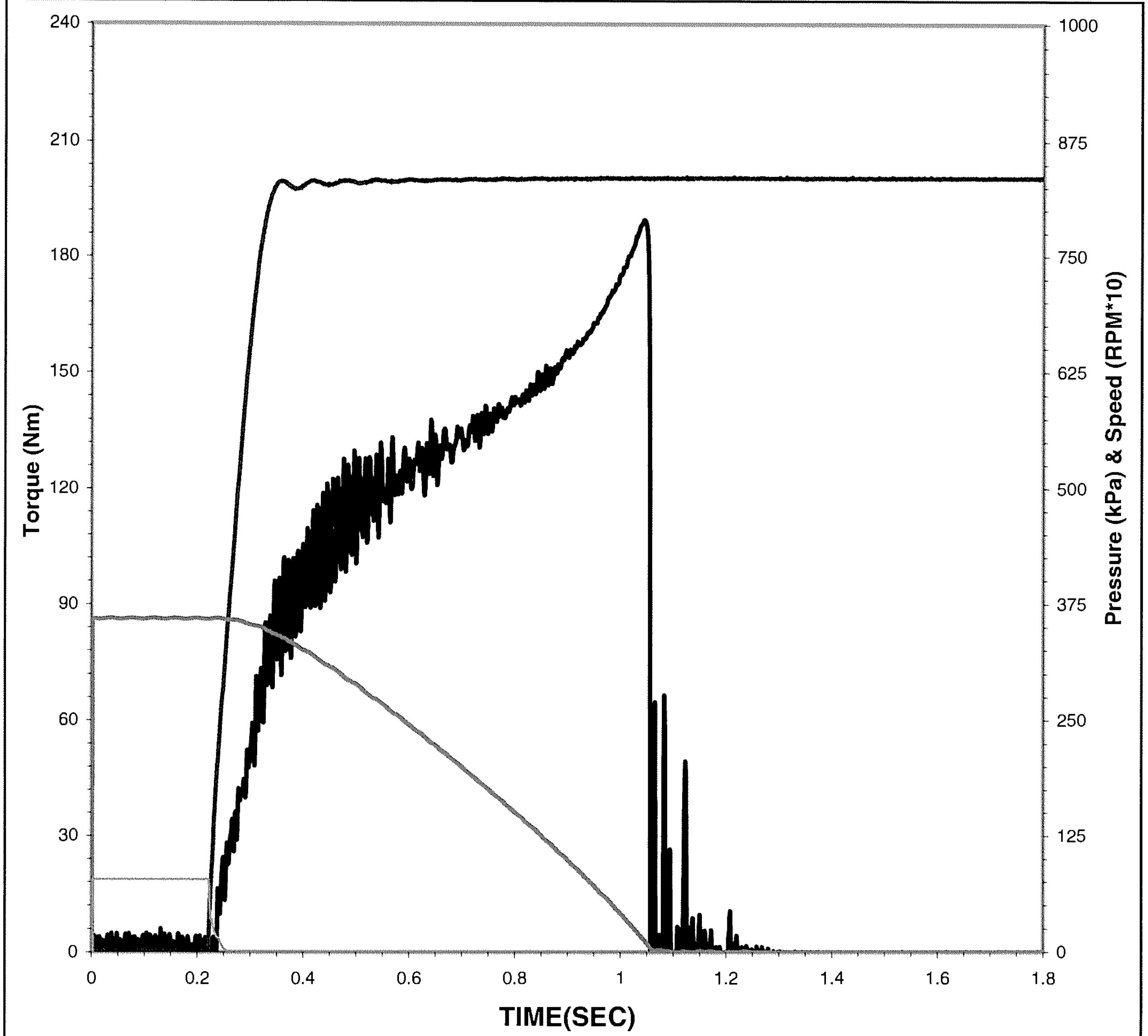
0.2 Sec Dyn:	103 N*m
Midpoint Dyn:	127 N*m
LwSpd Dynamic:	179 N*m

Coefficient of Friction

.2 Sec Dyn:	0.071
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.123

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	6:40:31
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	3500
Temperature:	110.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.836 Sec

Torque

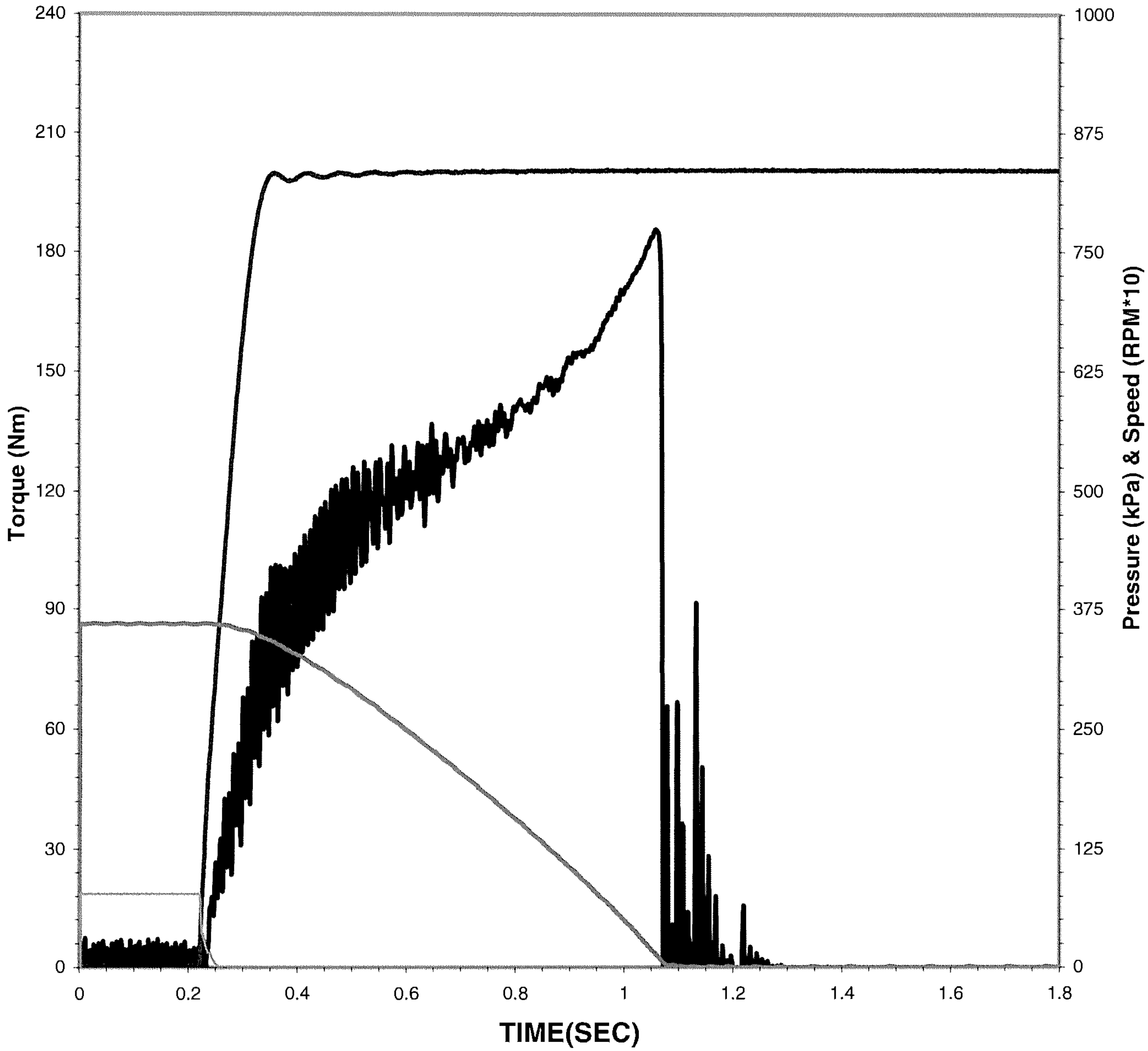
0.2 Sec Dyn:	103 N*m
Midpoint Dyn:	128 N*m
LwSpd Dynamic:	180 N*m

Coefficient of Friction

.2 Sec Dyn:	0.071
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.124

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	6:40:57
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	3501
Temperature:	106.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.851 Sec

Torque

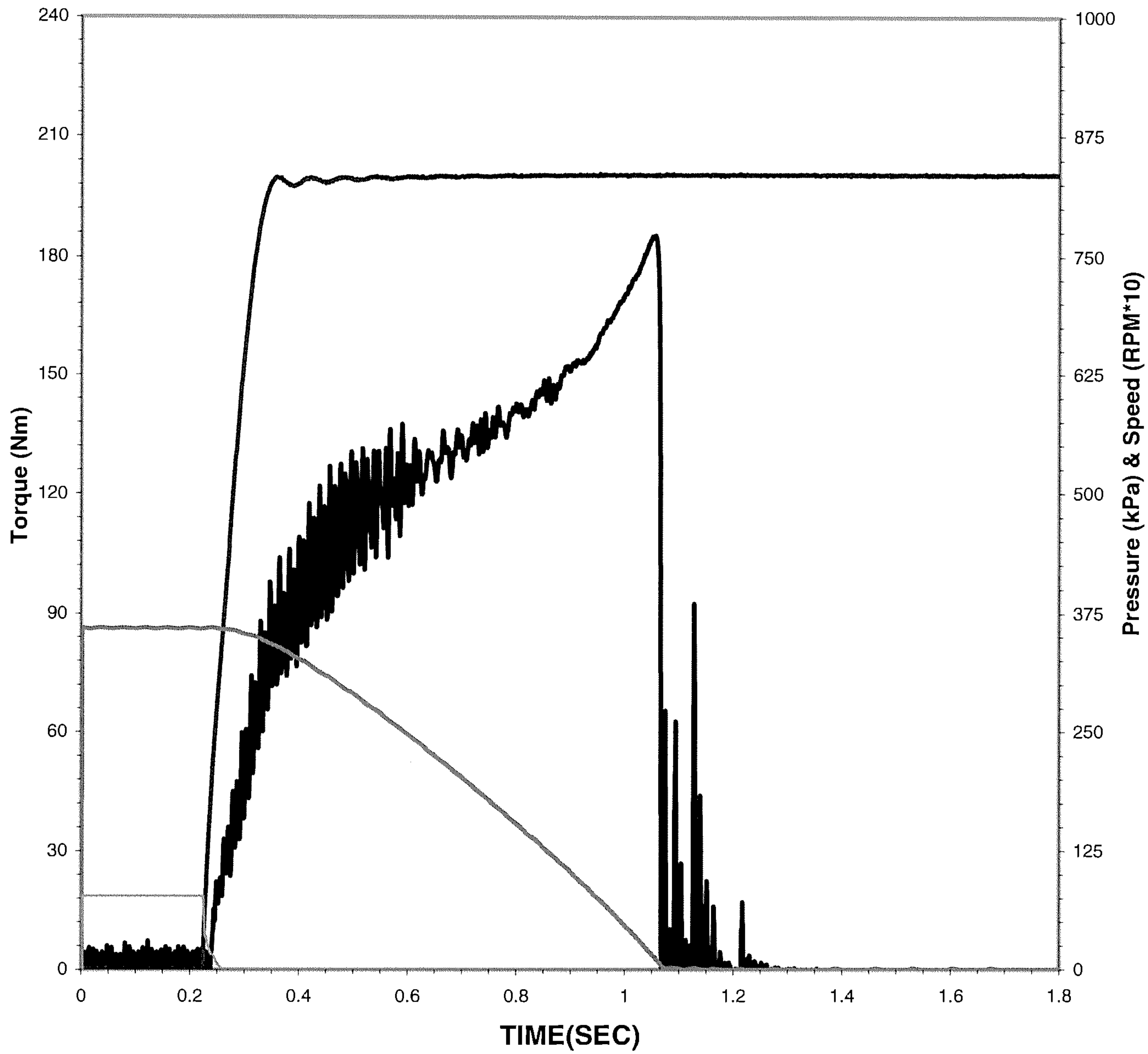
0.2 Sec Dyn:	96 N*m
Midpoint Dyn:	126 N*m
LwSpd Dynamic:	176 N*m

Coefficient of Friction

.2 Sec Dyn:	0.066
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.122

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	8:45:28
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	3999
Temperature:	110.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.843 Sec

Torque

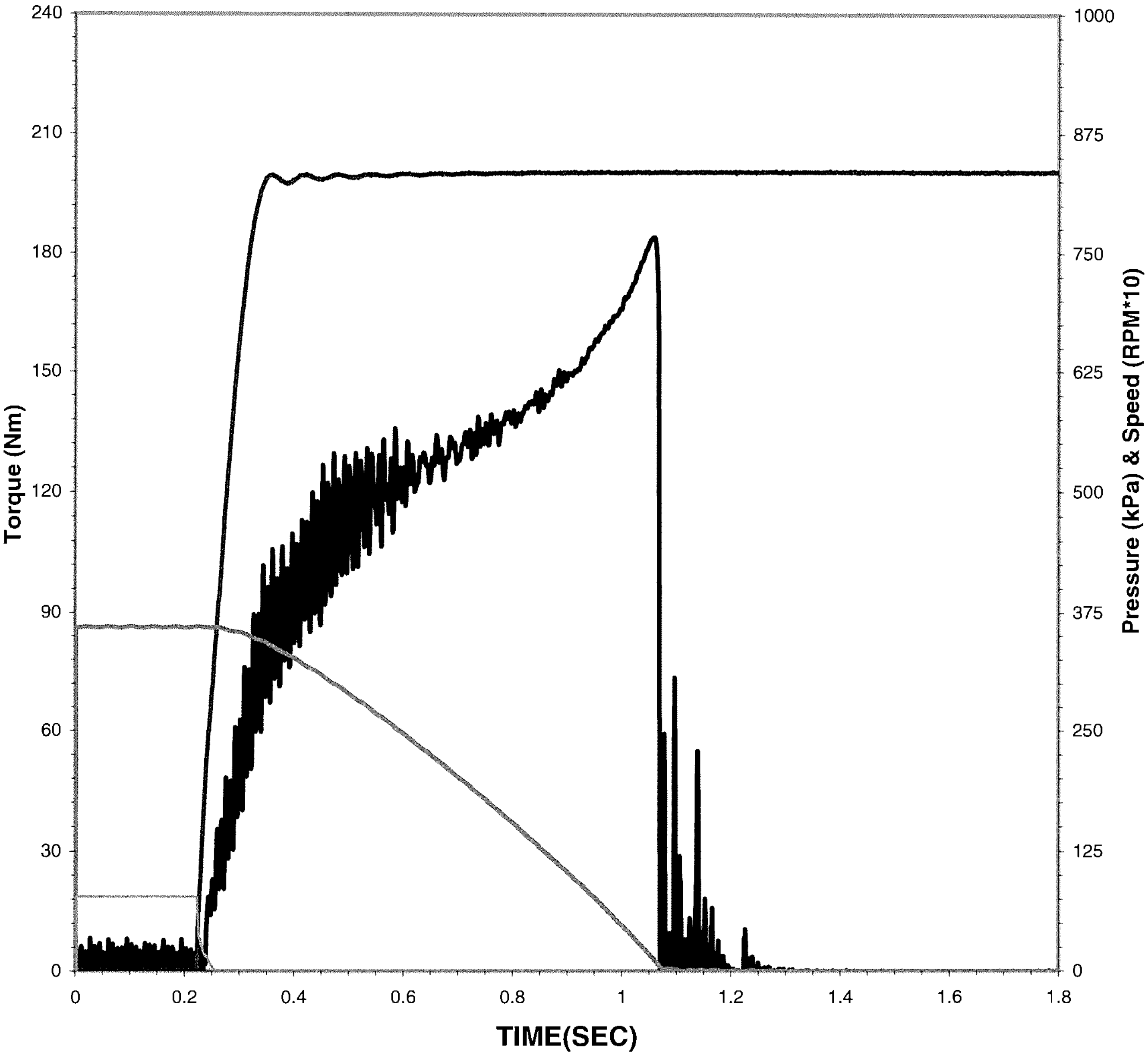
0.2 Sec Dyn:	102 N*m
Midpoint Dyn:	128 N*m
LwSpd Dynamic:	176 N*m

Coefficient of Friction

.2 Sec Dyn:	0.071
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.122

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	8:45:43
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	4000
Temperature:	110.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.848 Sec

Torque

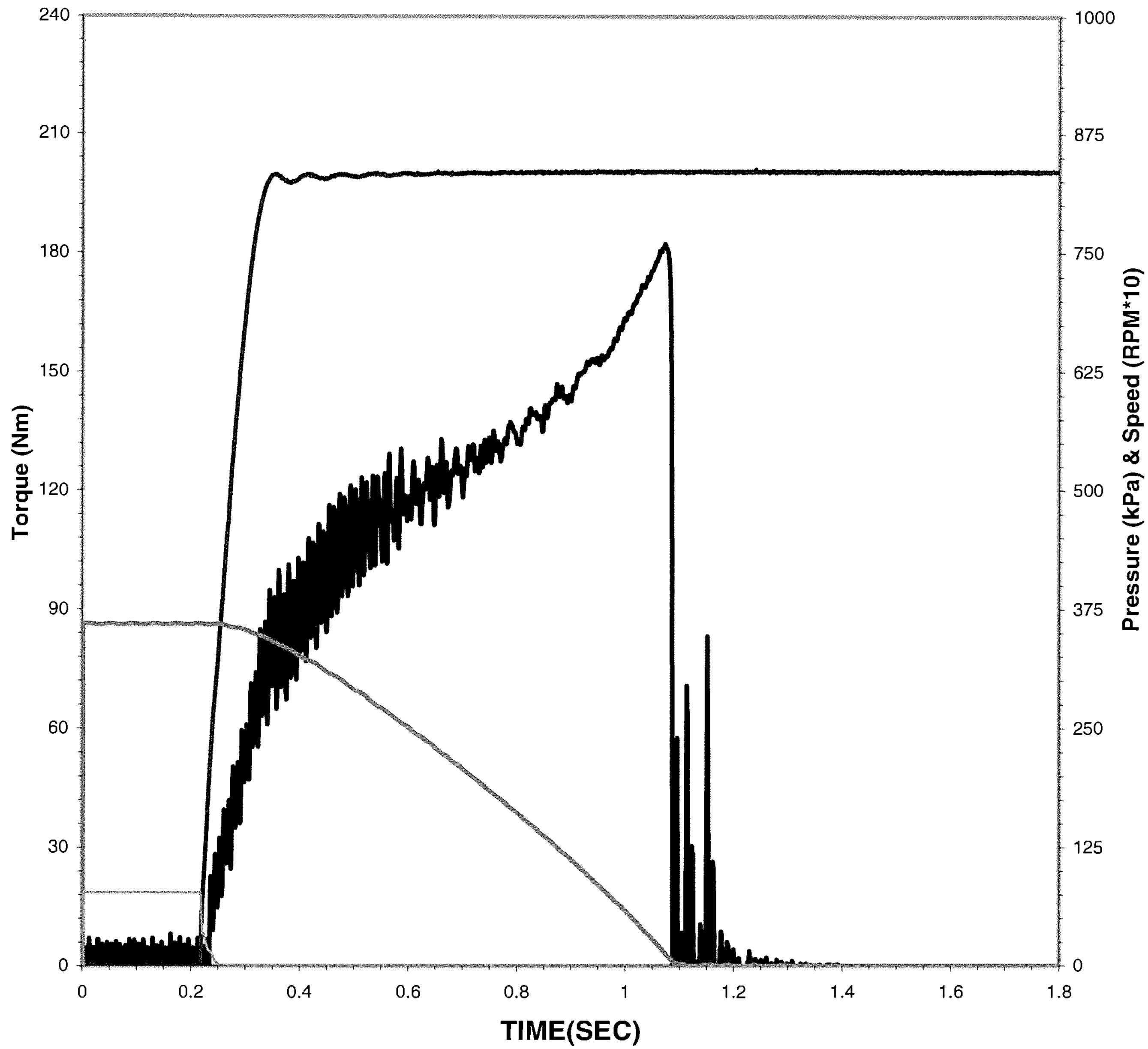
0.2 Sec Dyn:	100 N*m
Midpoint Dyn:	127 N*m
LwSpd Dynamic:	176 N*m

Coefficient of Friction

.2 Sec Dyn:	0.069
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.122

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	8:46:09
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	4001
Temperature:	106.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.87 Sec

Torque

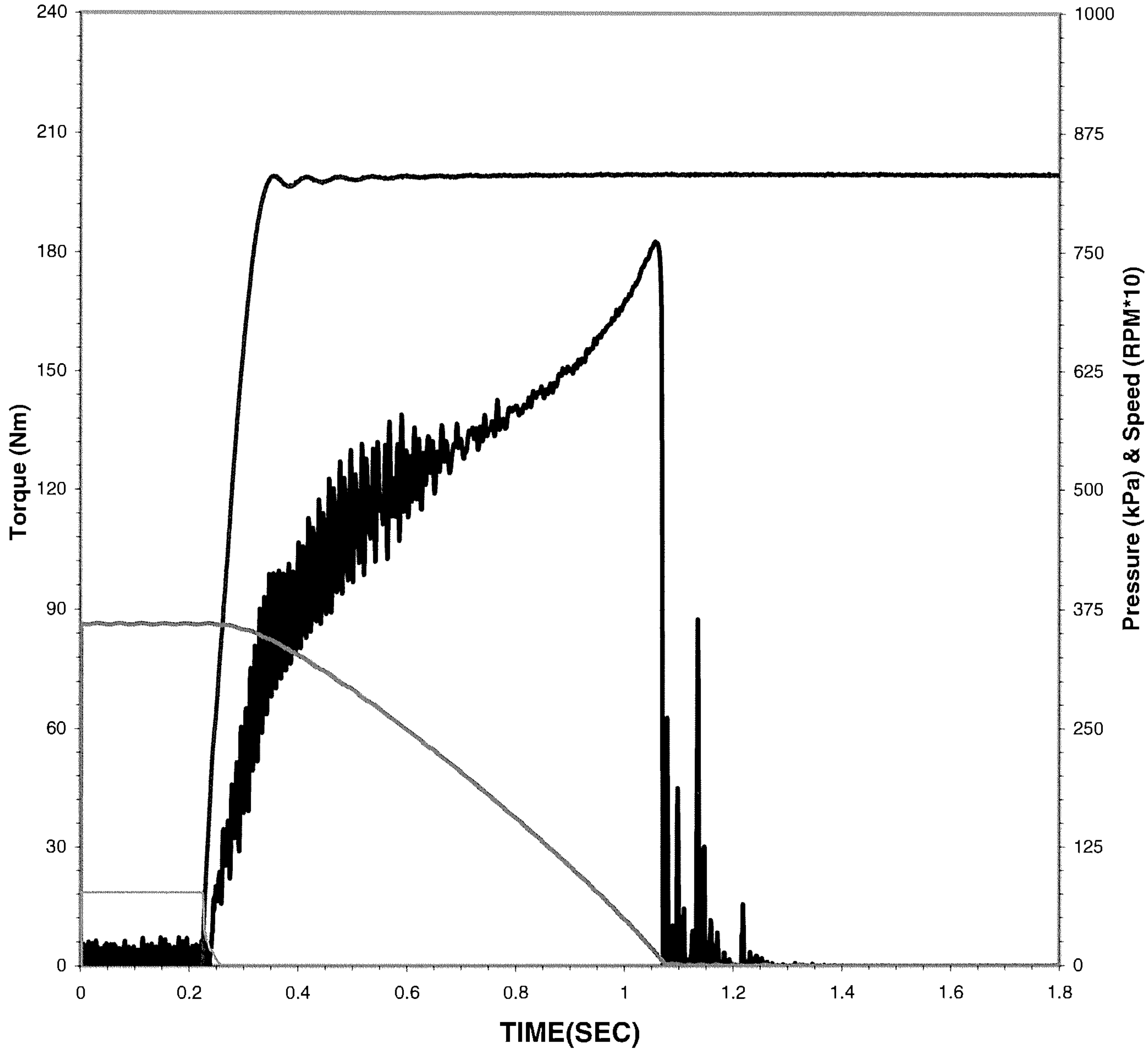
0.2 Sec Dyn:	95 N*m
Midpoint Dyn:	123 N*m
LwSpd Dynamic:	175 N*m

Coefficient of Friction

.2 Sec Dyn:	0.065
Midpoint Dyn:	0.085
LwSpd Dynamic:	0.121

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**10/14/2011**
Time of Test:	**10:50:39**
Test Number:	**C4-3-1341**
Fluid Code:	**LO268869**
Cycle Number:	**4499**
Temperature:	**111.6 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**830 kPa** 827 ± 7 KPa)
Apply Rate:	**0.12 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.846 Sec**

Torque

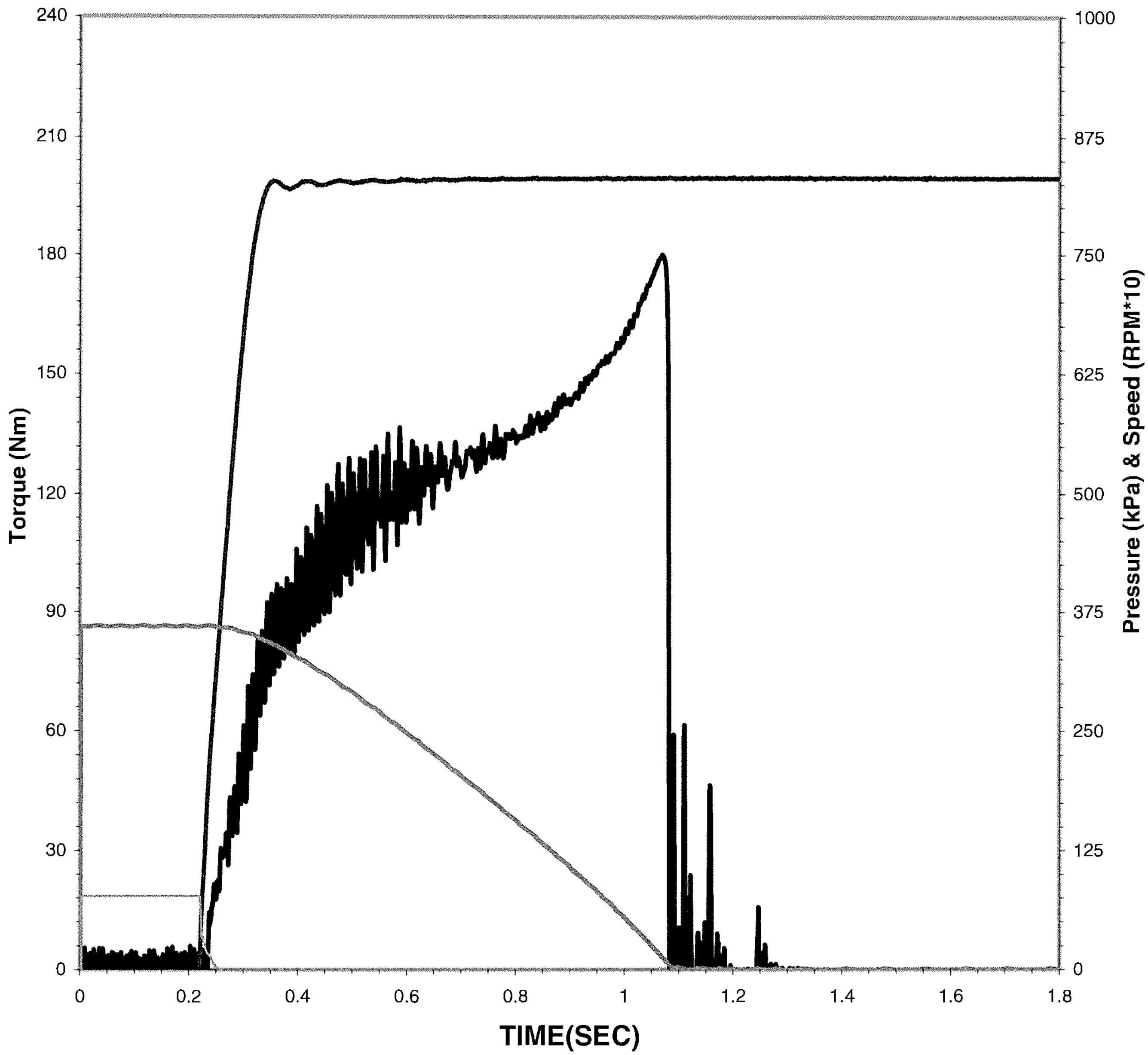
0.2 Sec Dyn:	**99 N*m**
Midpoint Dyn:	**128 N*m**
LwSpd Dynamic:	**173 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.069**
Midpoint Dyn:	**0.088**
LwSpd Dynamic:	**0.120**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	10:50:54
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	4500
Temperature:	110.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.863 Sec

Torque

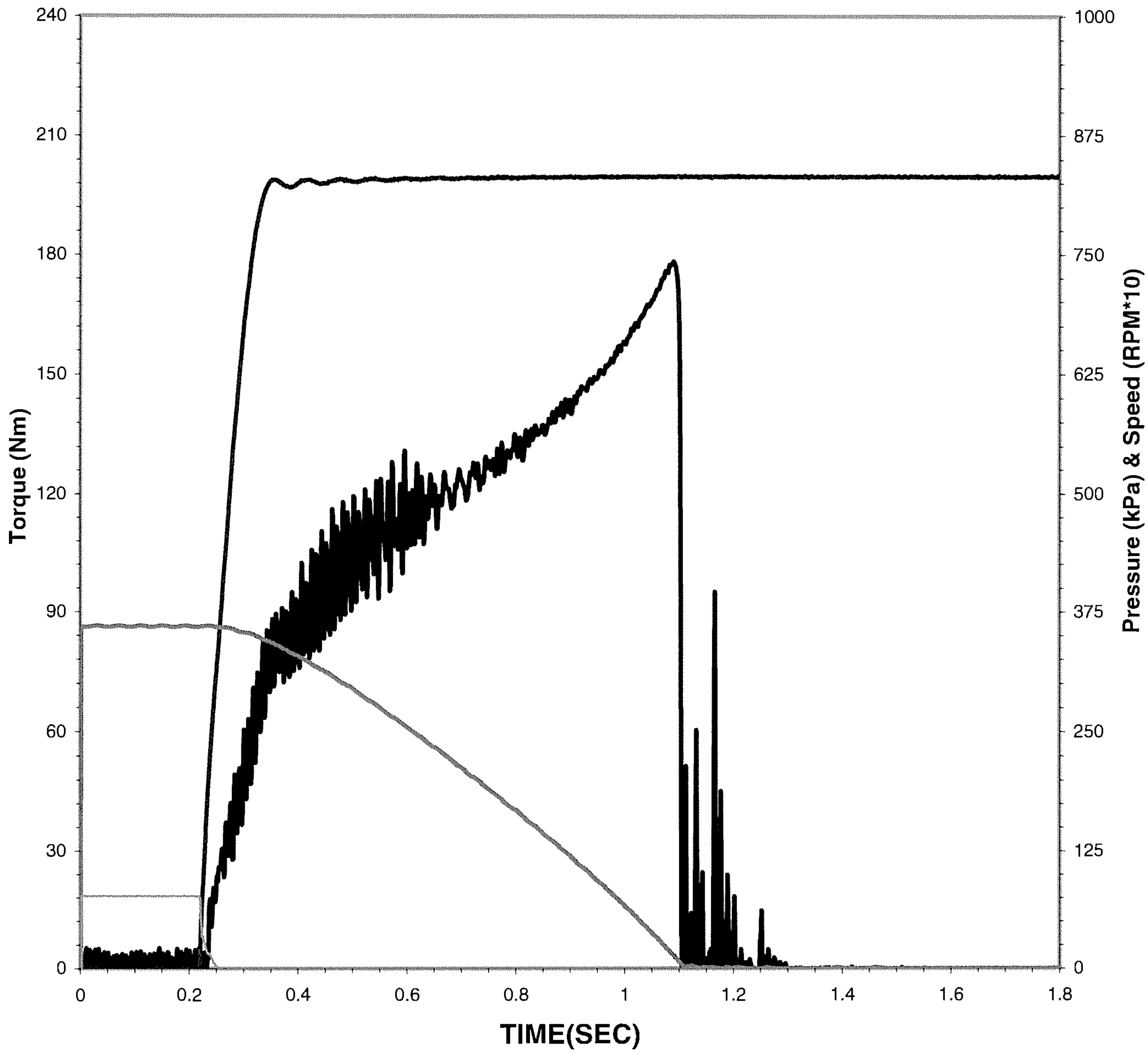
0.2 Sec Dyn:	99 N*m
Midpoint Dyn:	126 N*m
LwSpd Dynamic:	171 N*m

Coefficient of Friction

.2 Sec Dyn:	0.069
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.118

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 10/14/2011

Time of Test: 10:51:21

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 4501

Temperature: 106.4 °C
(112.7 ± 3.0 °C)

Apply Pressure: 830 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.885 Sec

Torque

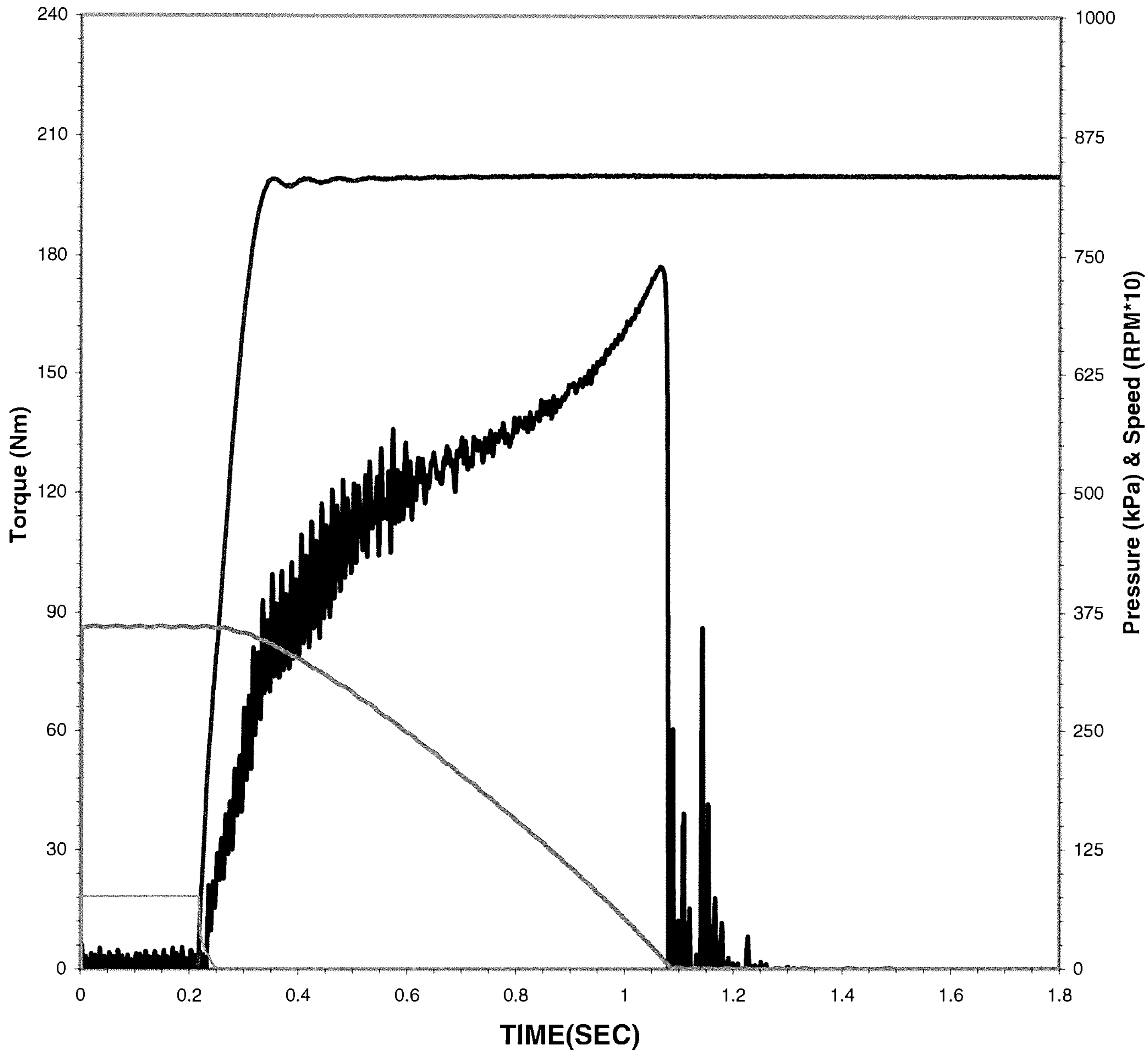
0.2 Sec Dyn:	92 N*m
Midpoint Dyn:	120 N*m
LwSpd Dynamic:	169 N*m

Coefficient of Friction

.2 Sec Dyn:	0.064
Midpoint Dyn:	0.083
LwSpd Dynamic:	0.117

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	12:55:51
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	4999
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.864 Sec

Torque

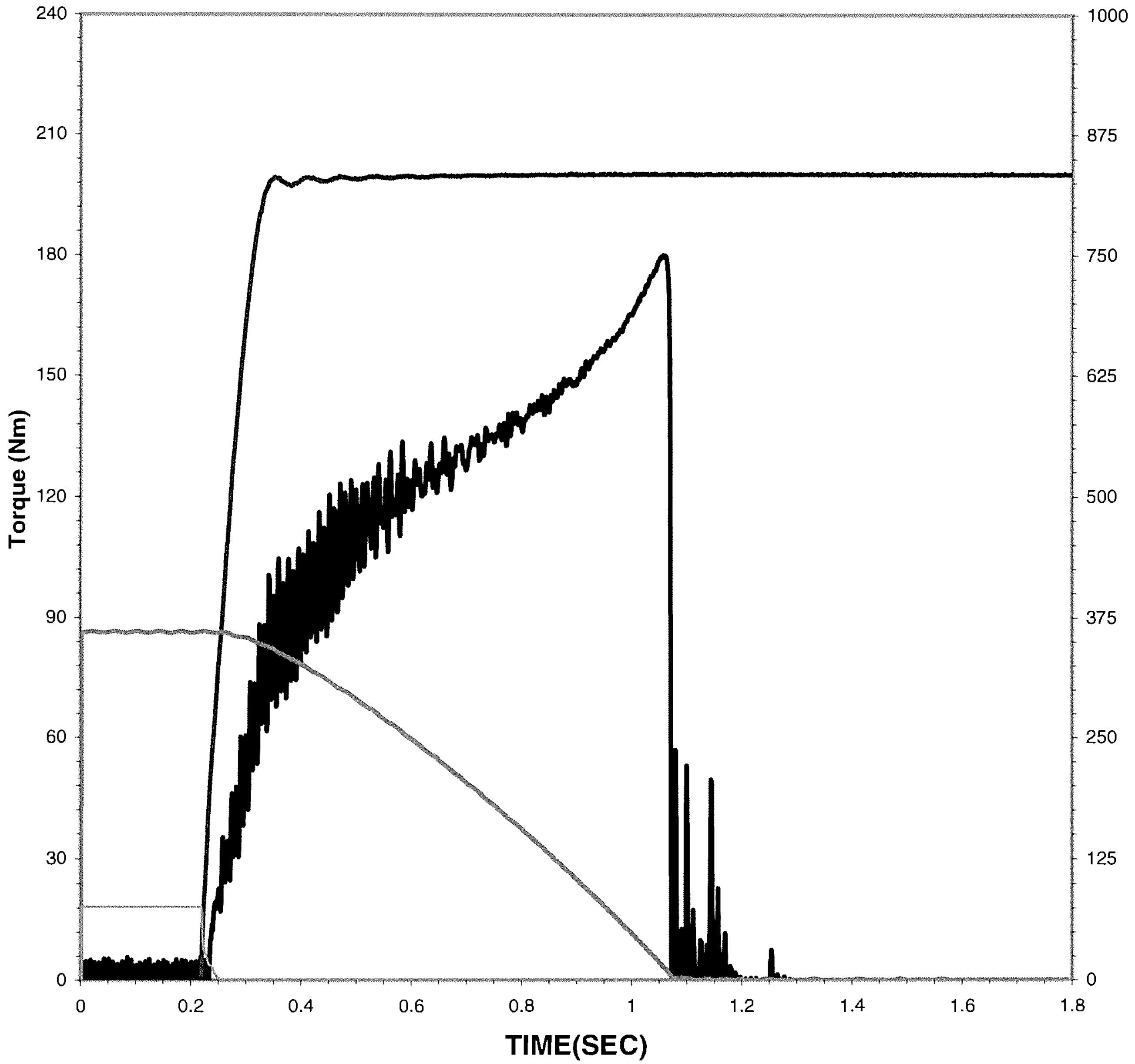
0.2 Sec Dyn:	97 N*m
Midpoint Dyn:	126 N*m
LwSpd Dynamic:	166 N*m

Coefficient of Friction

.2 Sec Dyn:	0.067
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.115

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	12:56:06
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	5000
Temperature:	110.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.854 Sec

Torque

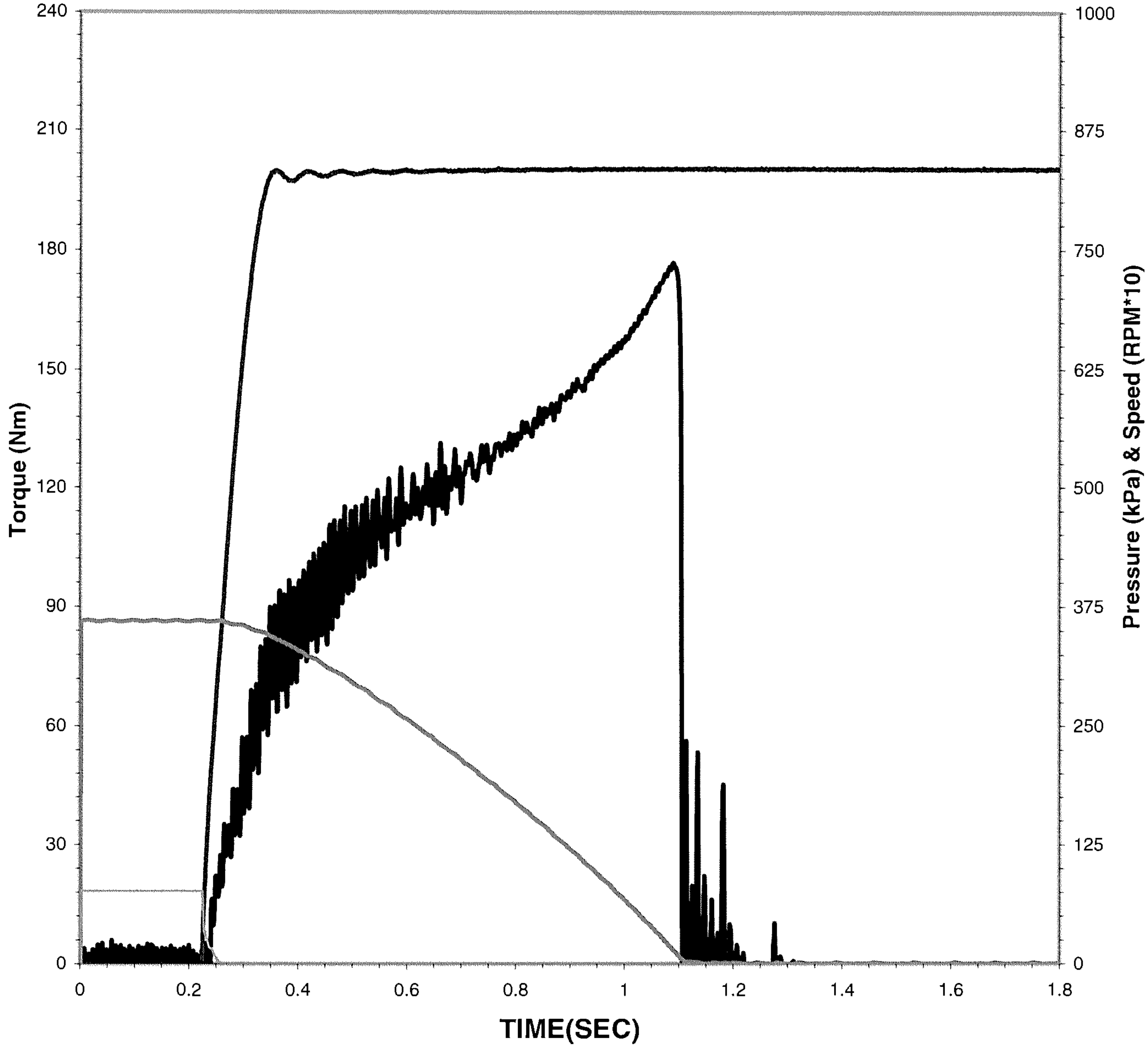
0.2 Sec Dyn:	99 N*m
Midpoint Dyn:	127 N*m
LwSpd Dynamic:	171 N*m

Coefficient of Friction

.2 Sec Dyn:	0.068
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.118

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	12:56:33
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	5001
Temperature:	106.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.882 Sec

Torque

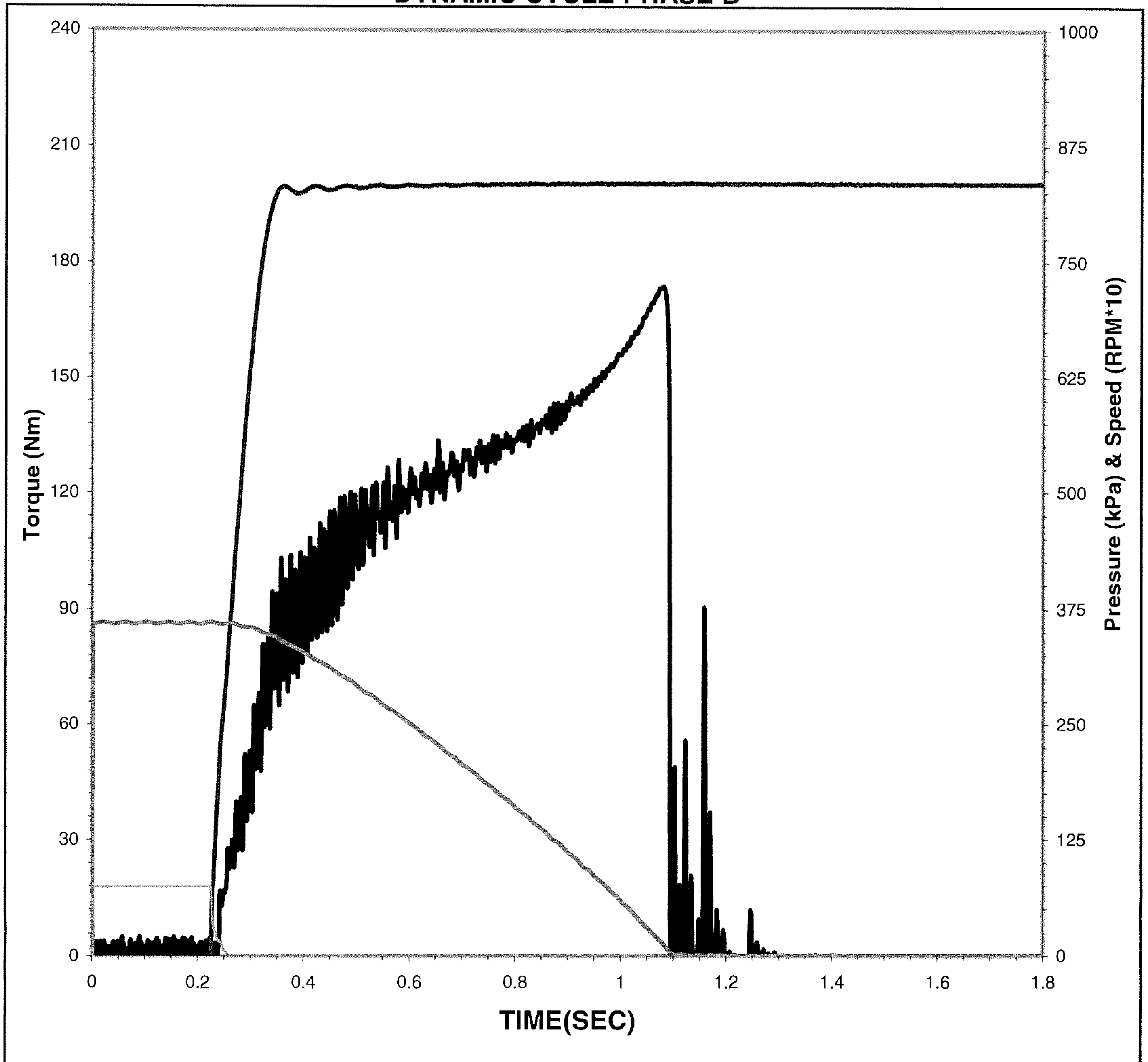
0.2 Sec Dyn:	92 N*m
Midpoint Dyn:	121 N*m
LwSpd Dynamic:	163 N*m

Coefficient of Friction

.2 Sec Dyn:	0.064
Midpoint Dyn:	0.083
LwSpd Dynamic:	0.113

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	15:00:48
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	5498
Temperature:	110.8 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	833 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.87 Sec

Torque

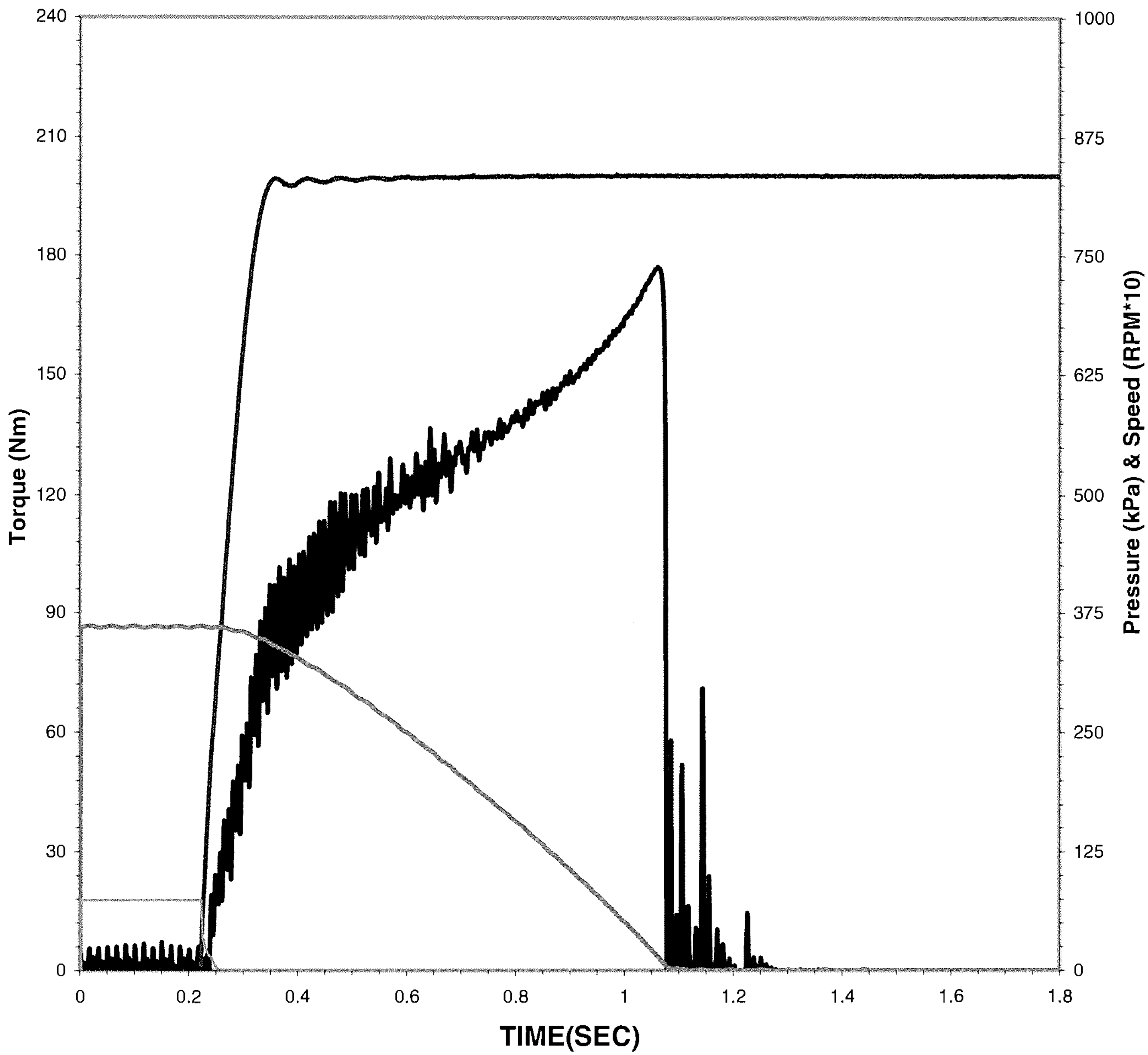
0.2 Sec Dyn:	98 N*m
Midpoint Dyn:	125 N*m
LwSpd Dynamic:	163 N*m

Coefficient of Friction

.2 Sec Dyn:	0.067
Midpoint Dyn:	0.086
LwSpd Dynamic:	0.113

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	15:01:03
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	5499
Temperature:	110.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.855 Sec

Torque

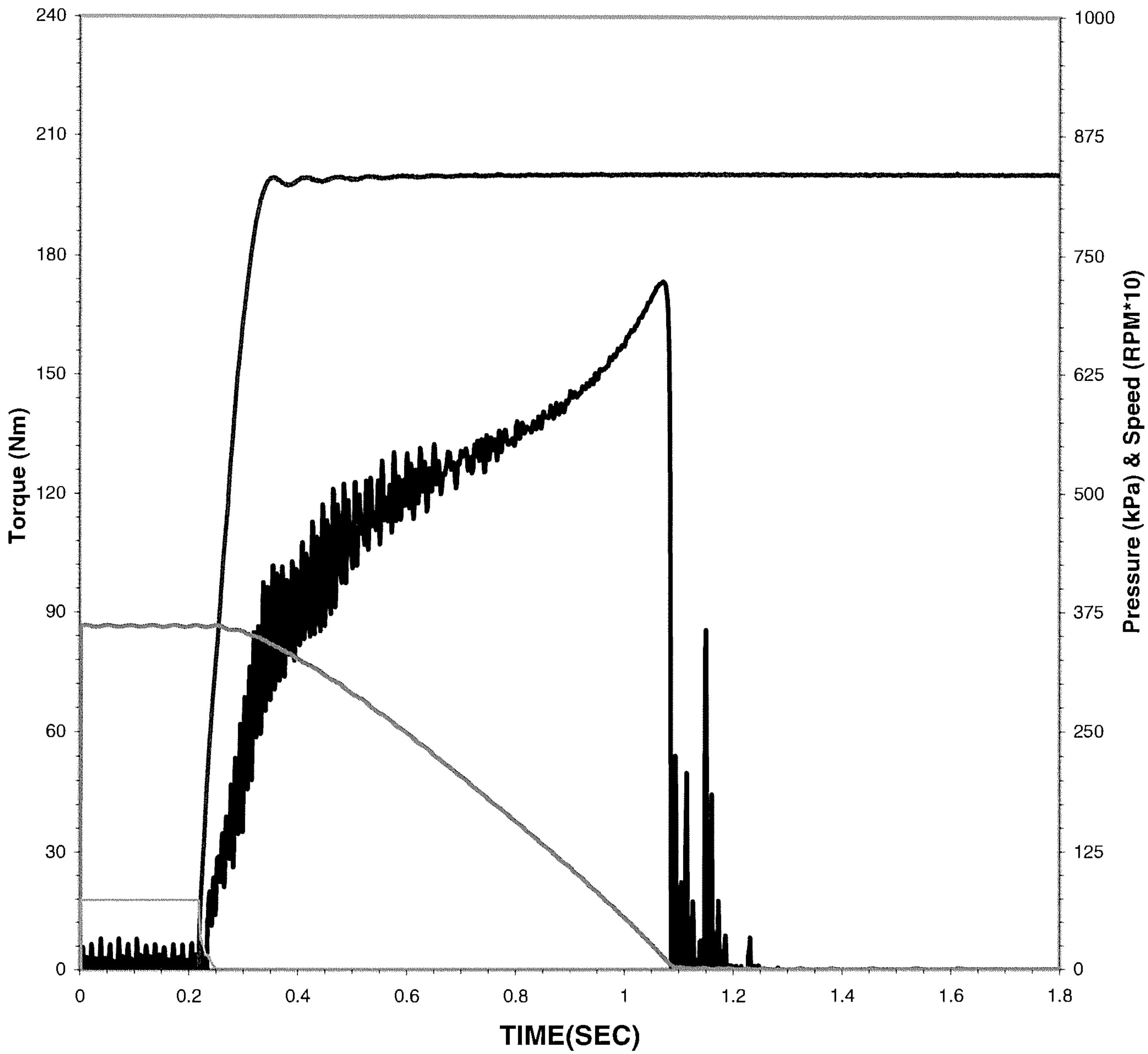
0.2 Sec Dyn:	98 N*m
Midpoint Dyn:	126 N*m
LwSpd Dynamic:	167 N*m

Coefficient of Friction

.2 Sec Dyn:	0.068
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.116

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	15:01:18
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	5500
Temperature:	110.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.869 Sec

Torque

0.2 Sec Dyn:	96 N*m
Midpoint Dyn:	125 N*m
LwSpd Dynamic:	163 N*m

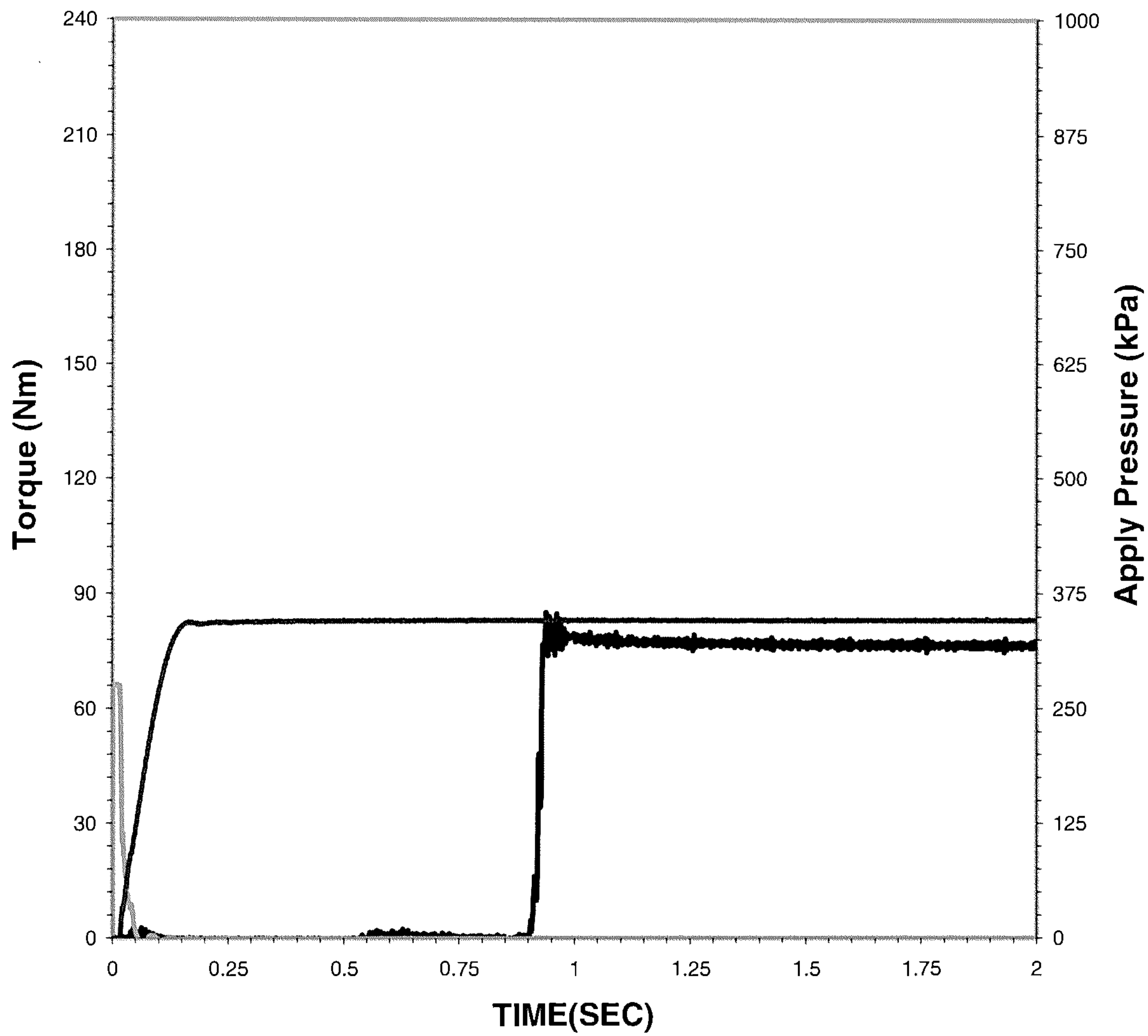
Coefficient of Friction

.2 Sec Dyn:	0.066
Midpoint Dyn:	0.086
LwSpd Dynamic:	0.112

STATIC TRACES

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/13/2011

Time of Test: 15:15:51

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 10

PHASE A

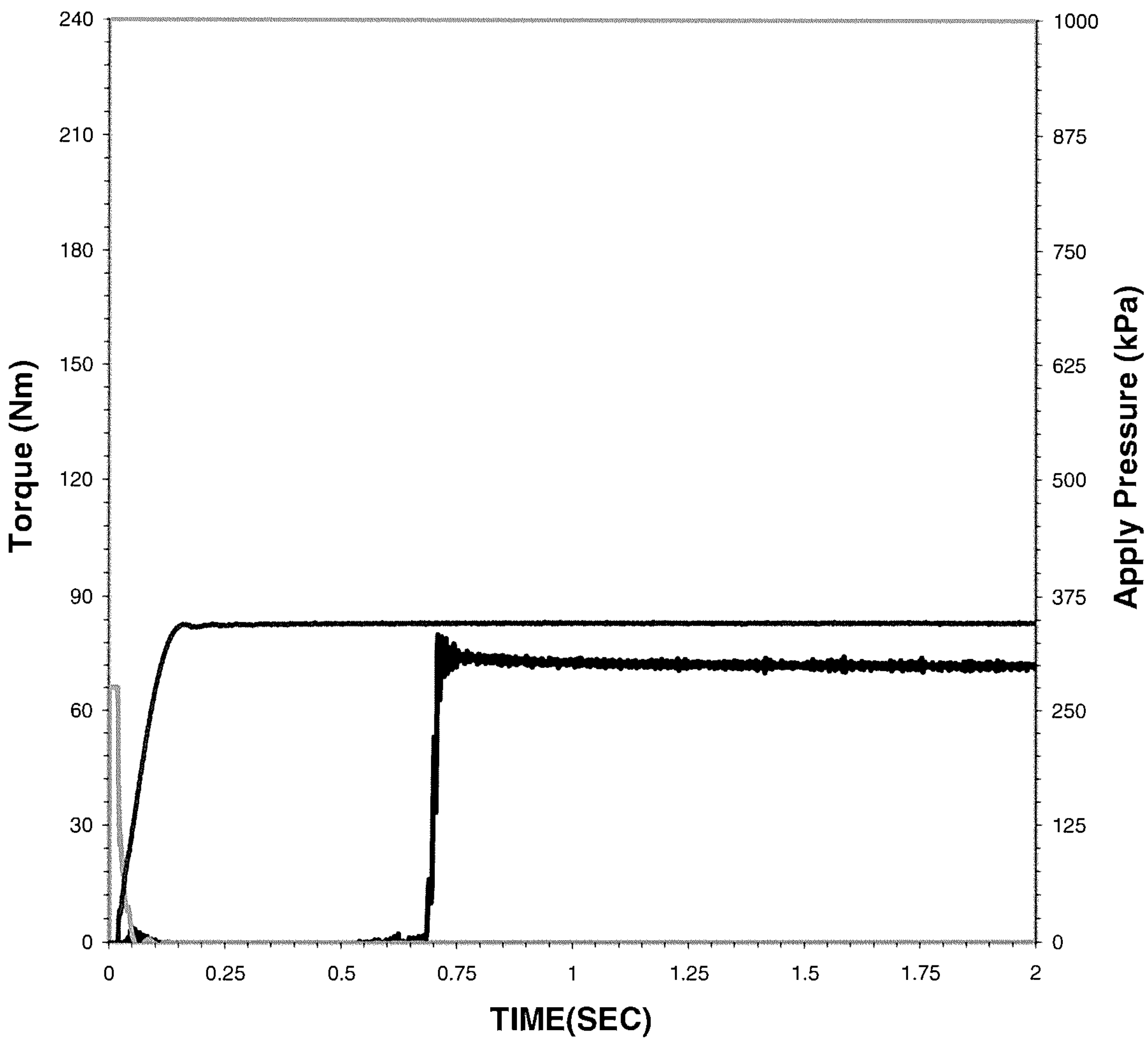
Apply Pressure:
At .25 Second: 347 kPa

Torque
Static Peak: 85 Nm
.25 Second: 78 Nm

Coefficient of Friction
Static Peak: 0.141
.25 Second: 0.129

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/13/2011

Time of Test: 17:18:33

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 500

PHASE A

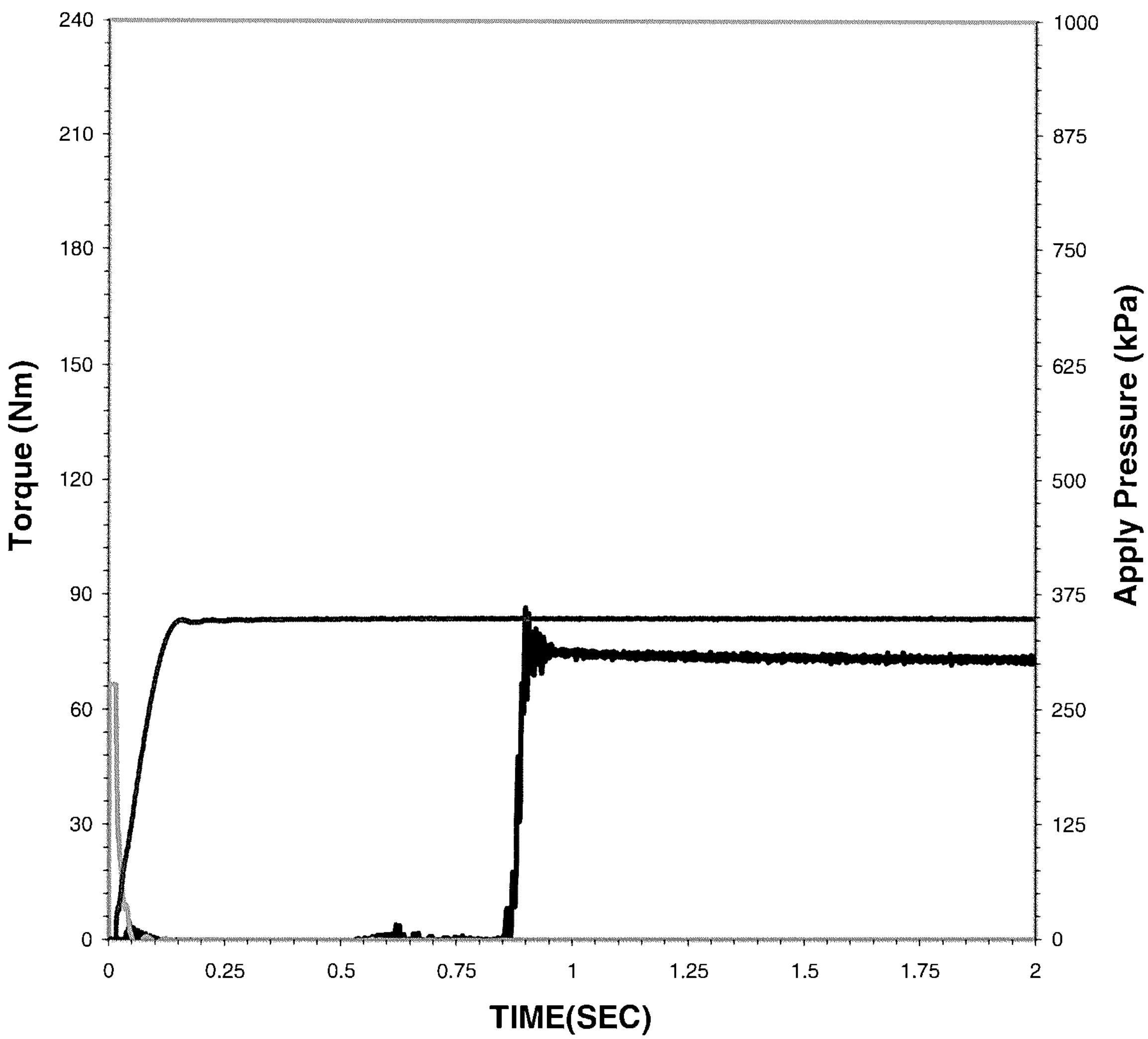
Apply Pressure:
At .25 Second: 347 kPa

Torque
Static Peak: 81 Nm
.25 Second: 73 Nm

Coefficient of Friction
Static Peak: 0.134
.25 Second: 0.120

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/13/2011

Time of Test: 19:23:45

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 1000

PHASE A

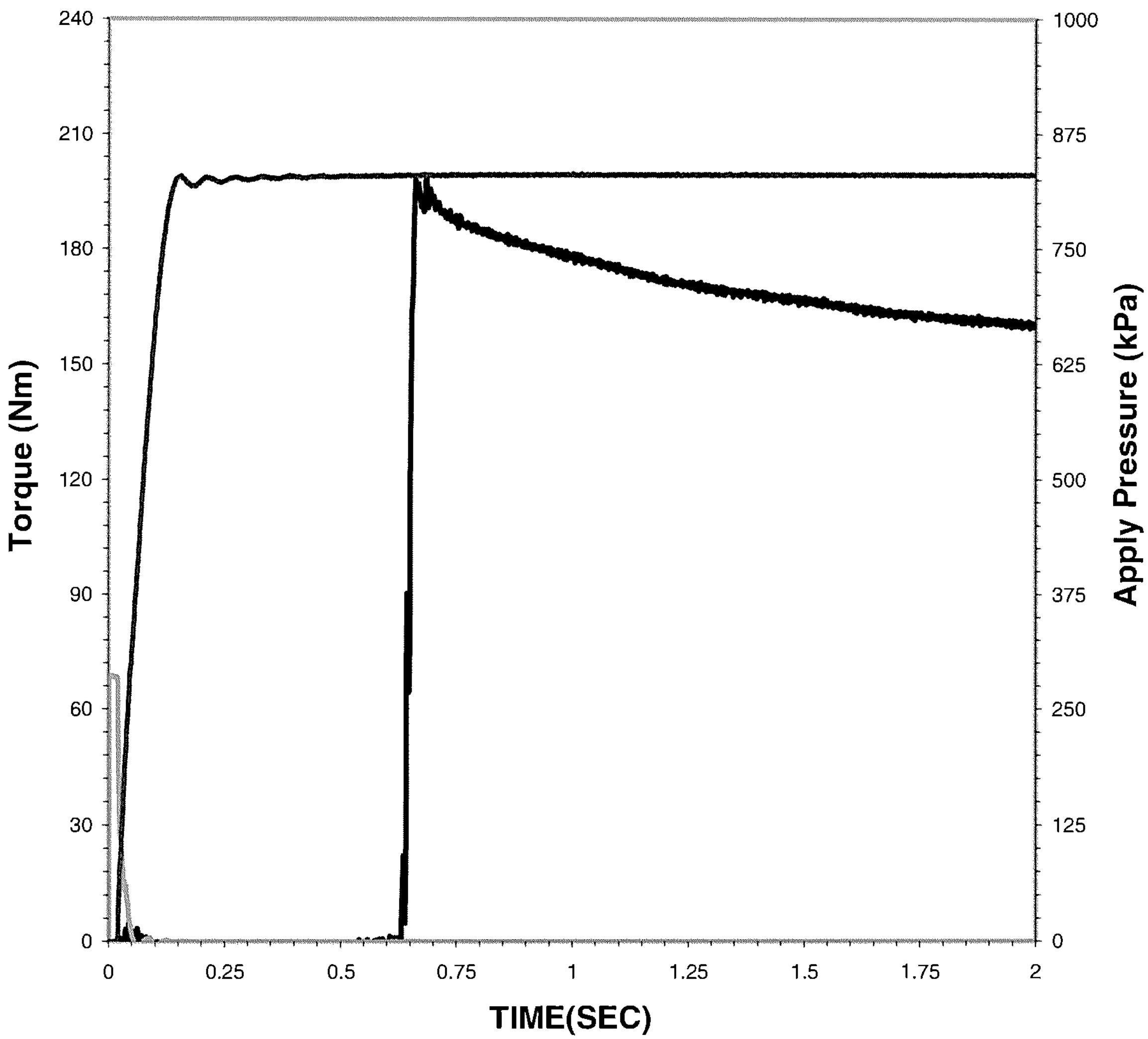
Apply Pressure:
At .25 Second: 348 kPa

Torque
Static Peak: 87 Nm
.25 Second: 75 Nm

Coefficient of Friction
Static Peak: 0.144
.25 Second: 0.125

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/13/2011

Time of Test: 22:19:55

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 1500

PHASE B

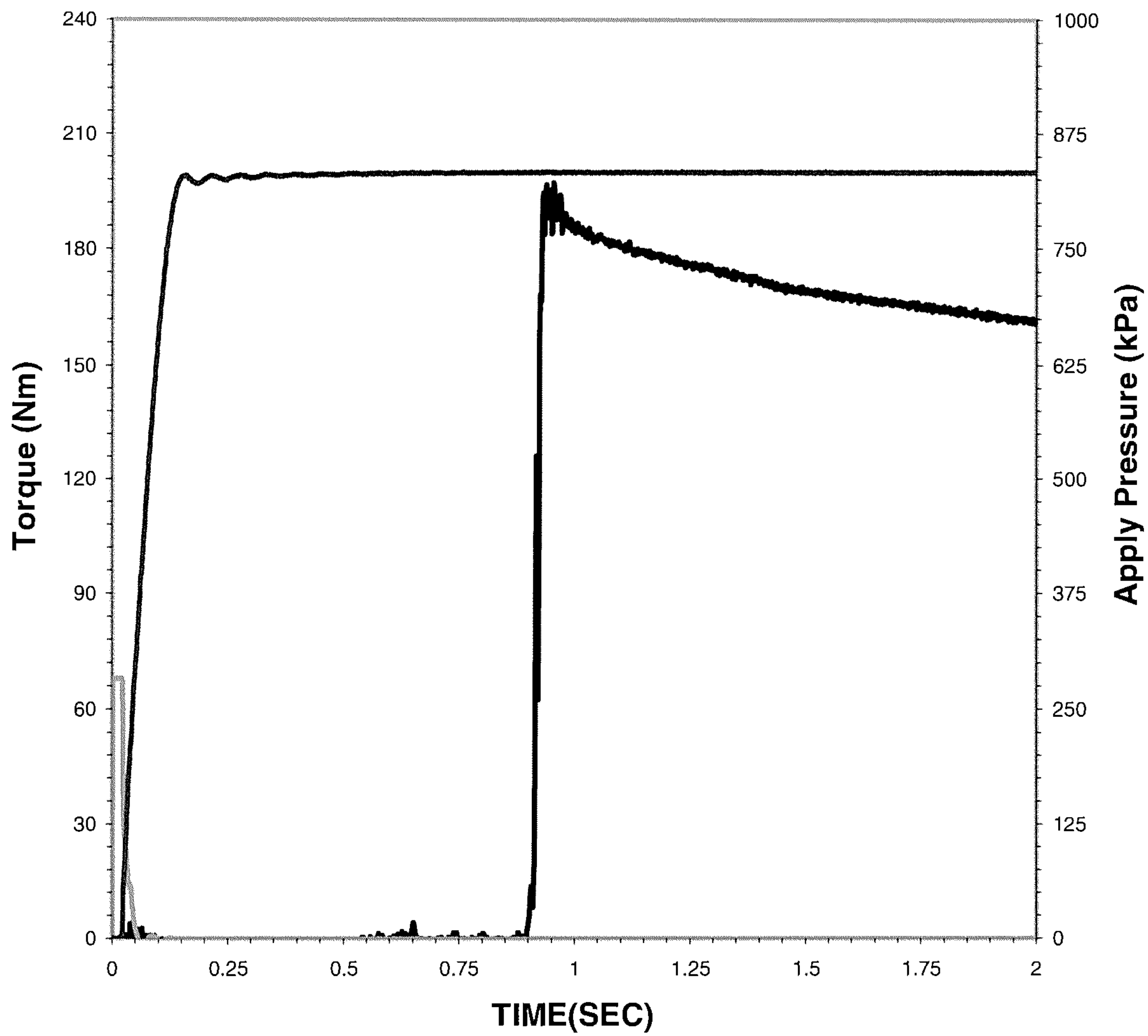
Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 199 Nm
.25 Second: 182 Nm

Coefficient of Friction
Static Peak: 0.137
.25 Second: 0.126

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test:	10/14/2011
Time of Test:	0:25:07
Test Number:	C4-3-1341
Fluid Code:	LO268869
Cycle Number:	2000

PHASE B

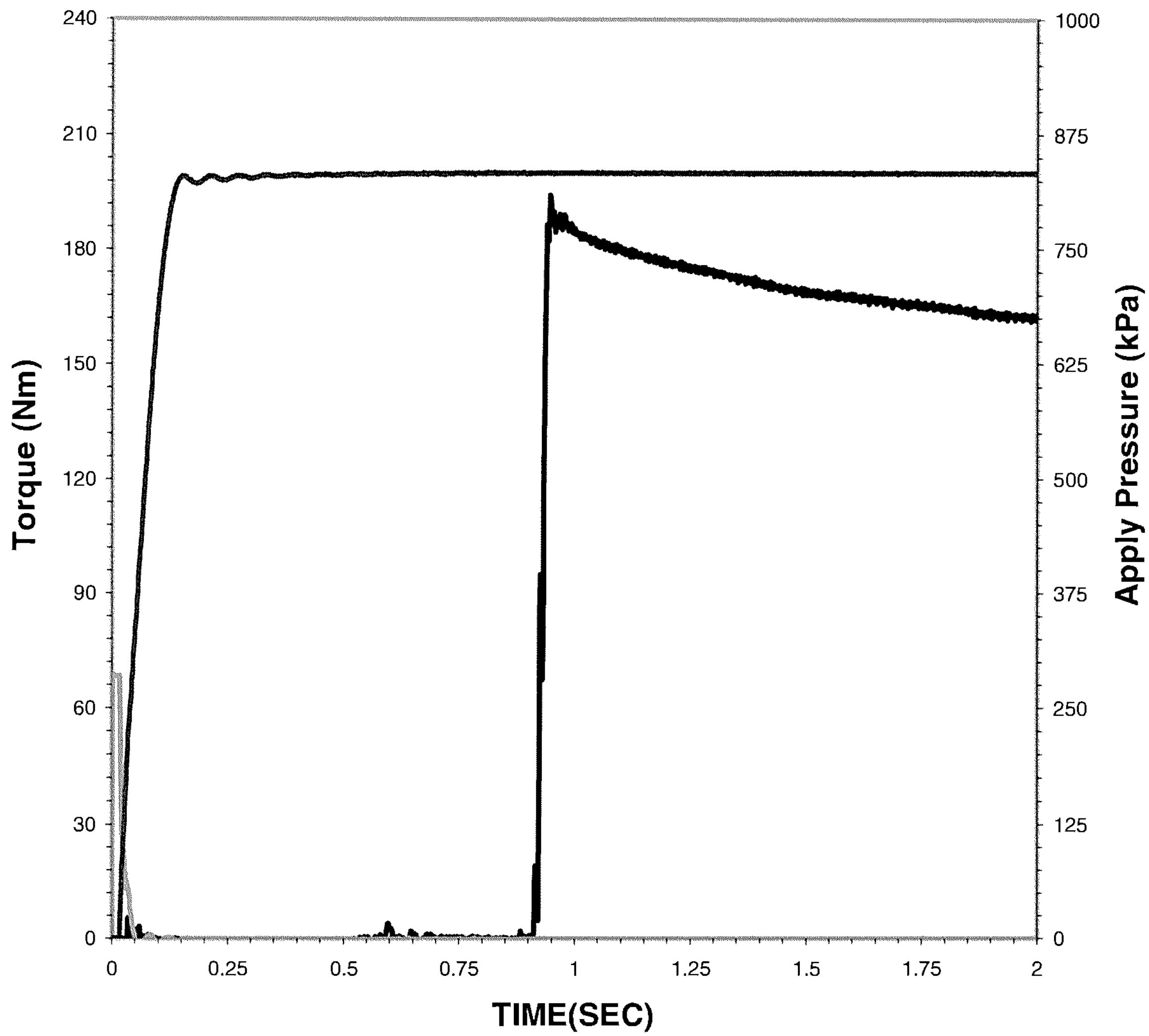
Apply Pressure:
At .25 Second: 830 kPa

Torque
Static Peak: 198 Nm
.25 Second: 179 Nm

Coefficient of Friction
Static Peak: 0.137
.25 Second: 0.124

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 2:30:19

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 2500

PHASE B

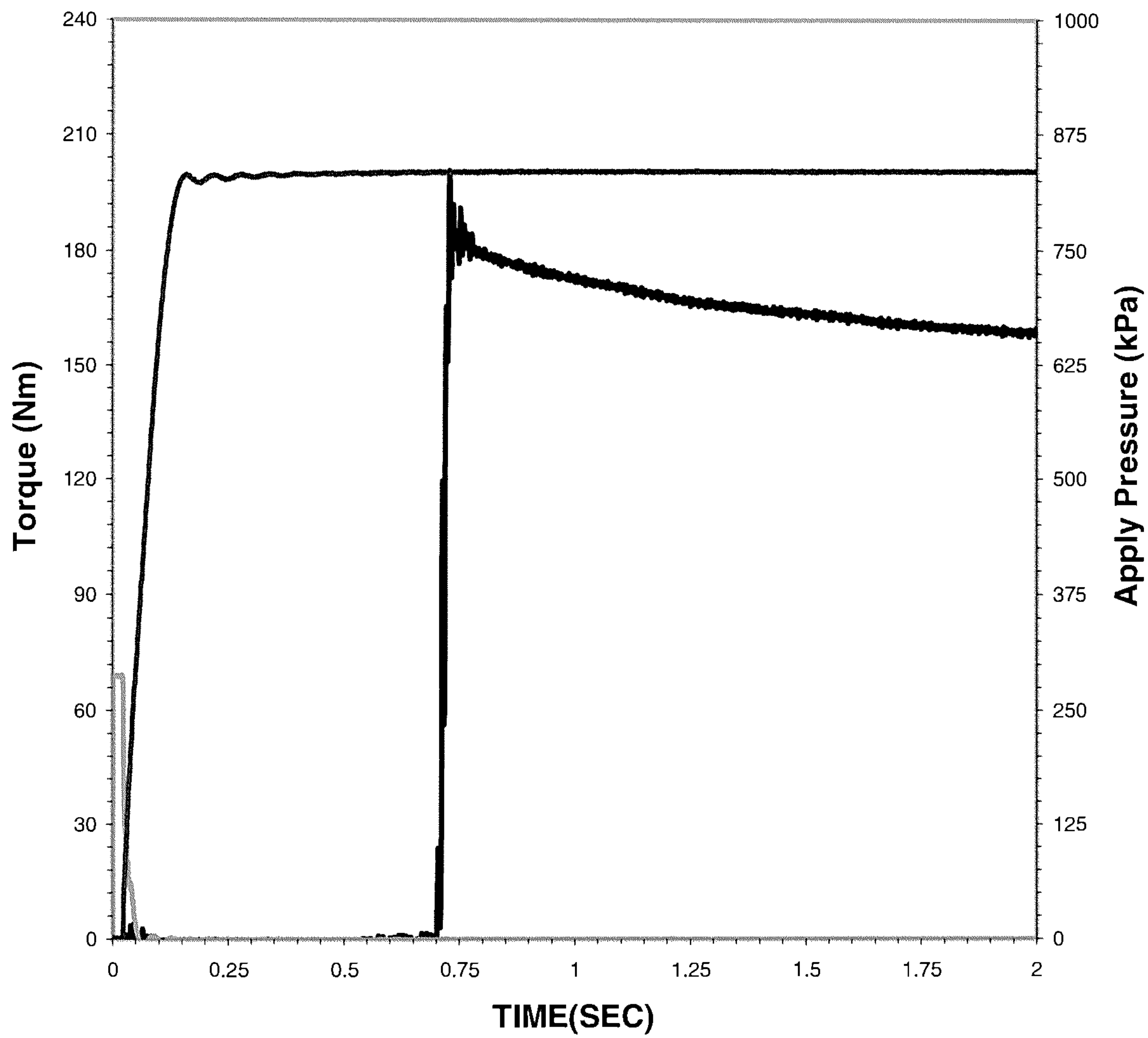
Apply Pressure:
At .25 Second: 830 kPa

Torque
Static Peak: 195 Nm
.25 Second: 178 Nm

Coefficient of Friction
Static Peak: 0.135
.25 Second: 0.123

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 4:35:31

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 3000

PHASE B

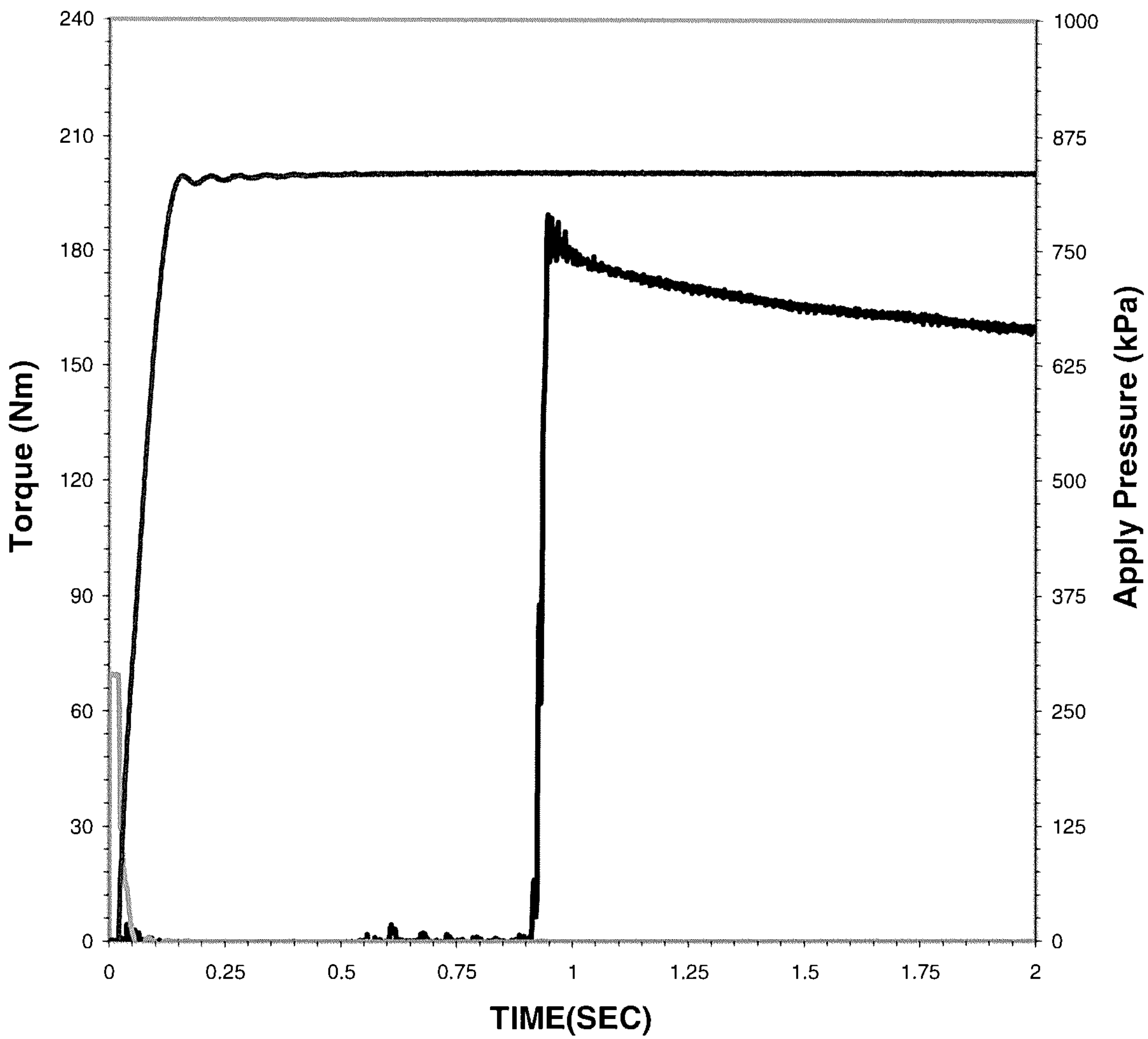
Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 201 Nm
.25 Second: 174 Nm

Coefficient of Friction
Static Peak: 0.139
.25 Second: 0.120

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 6:40:42

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 3500

PHASE B

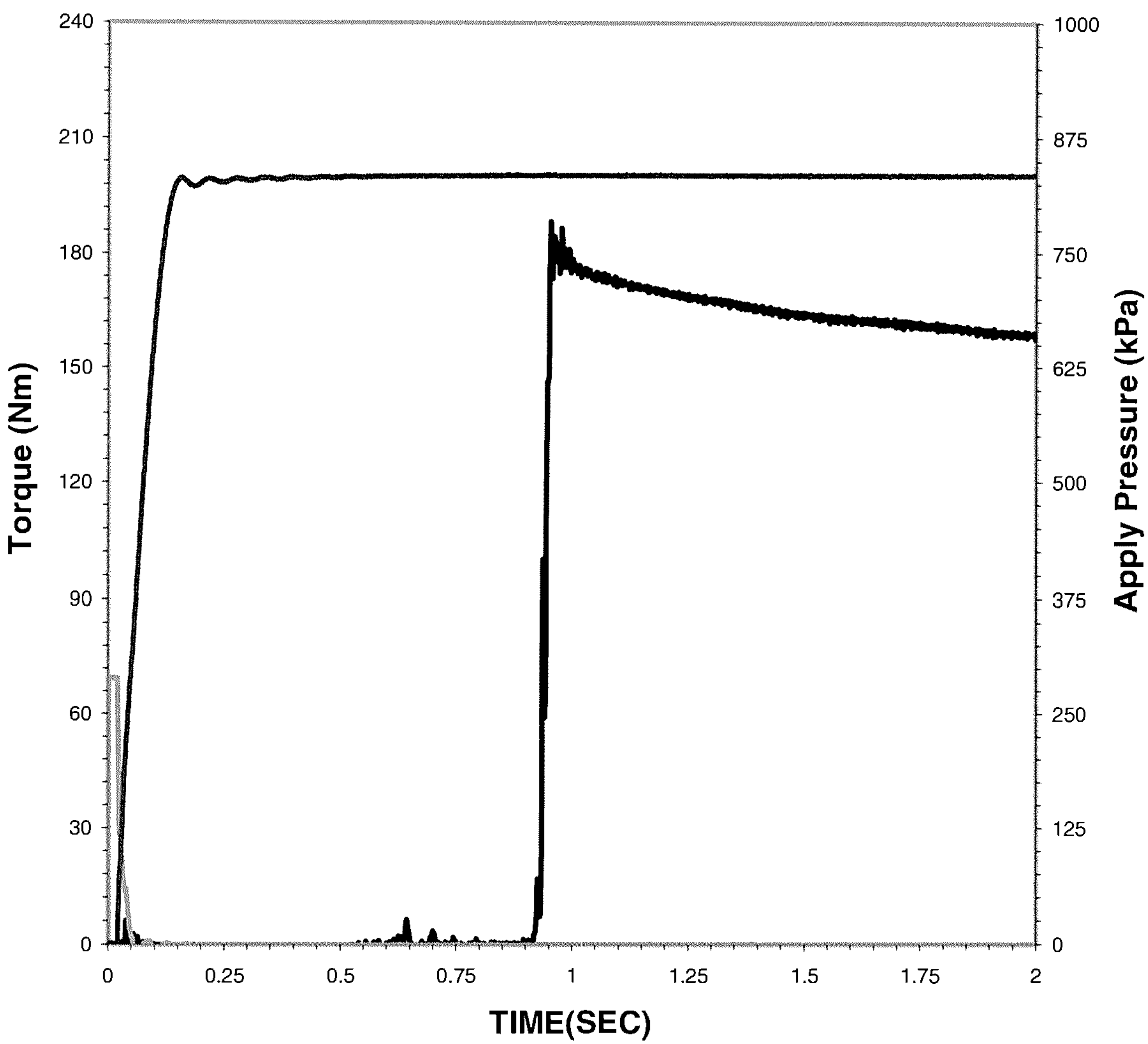
Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 190 Nm
.25 Second: 174 Nm

Coefficient of Friction
Static Peak: 0.131
.25 Second: 0.120

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 8:45:54

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 4000

PHASE B

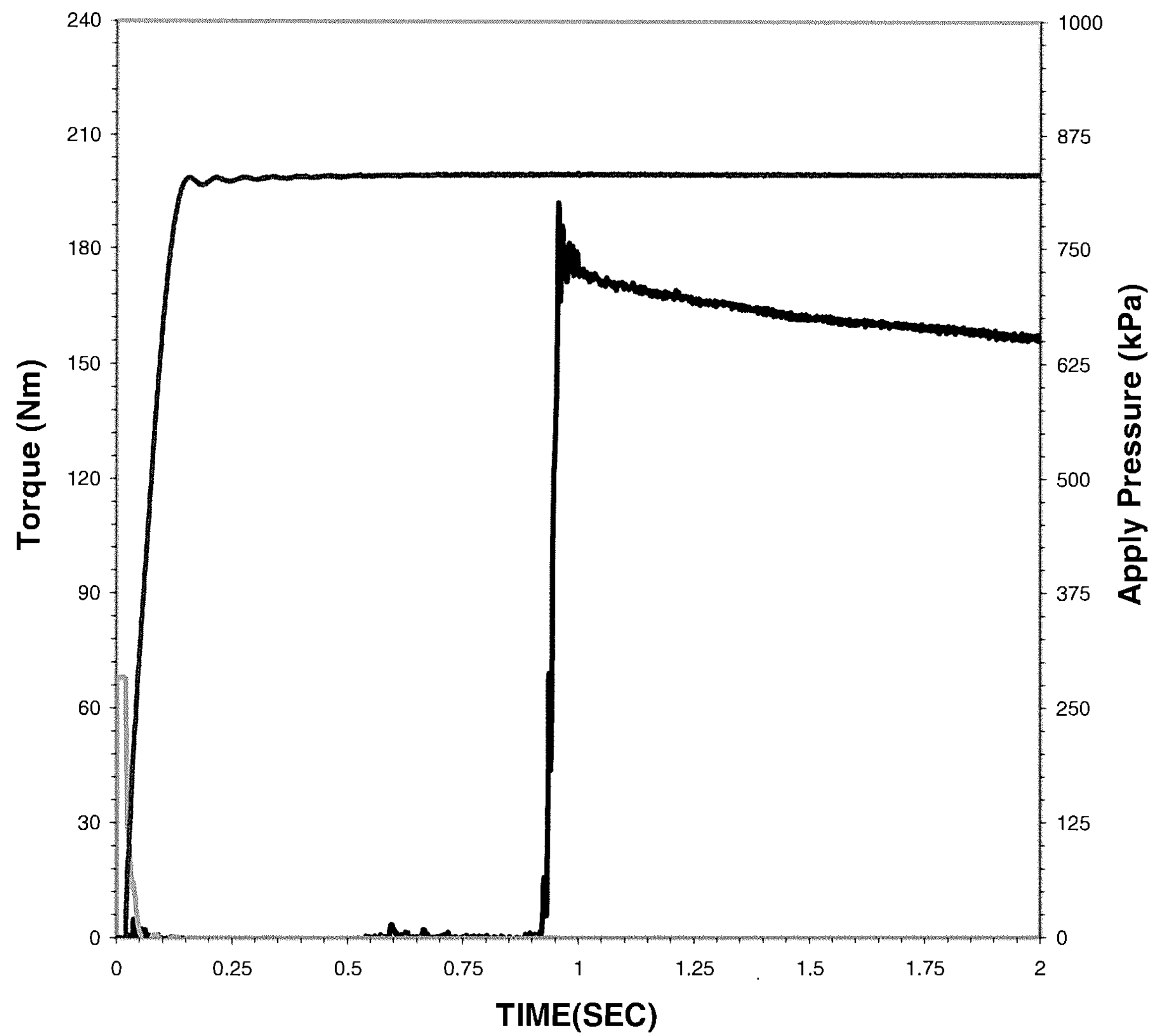
Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 189 Nm
.25 Second: 171 Nm

Coefficient of Friction
Static Peak: 0.130
.25 Second: 0.118

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 10:51:06

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 4500

PHASE B

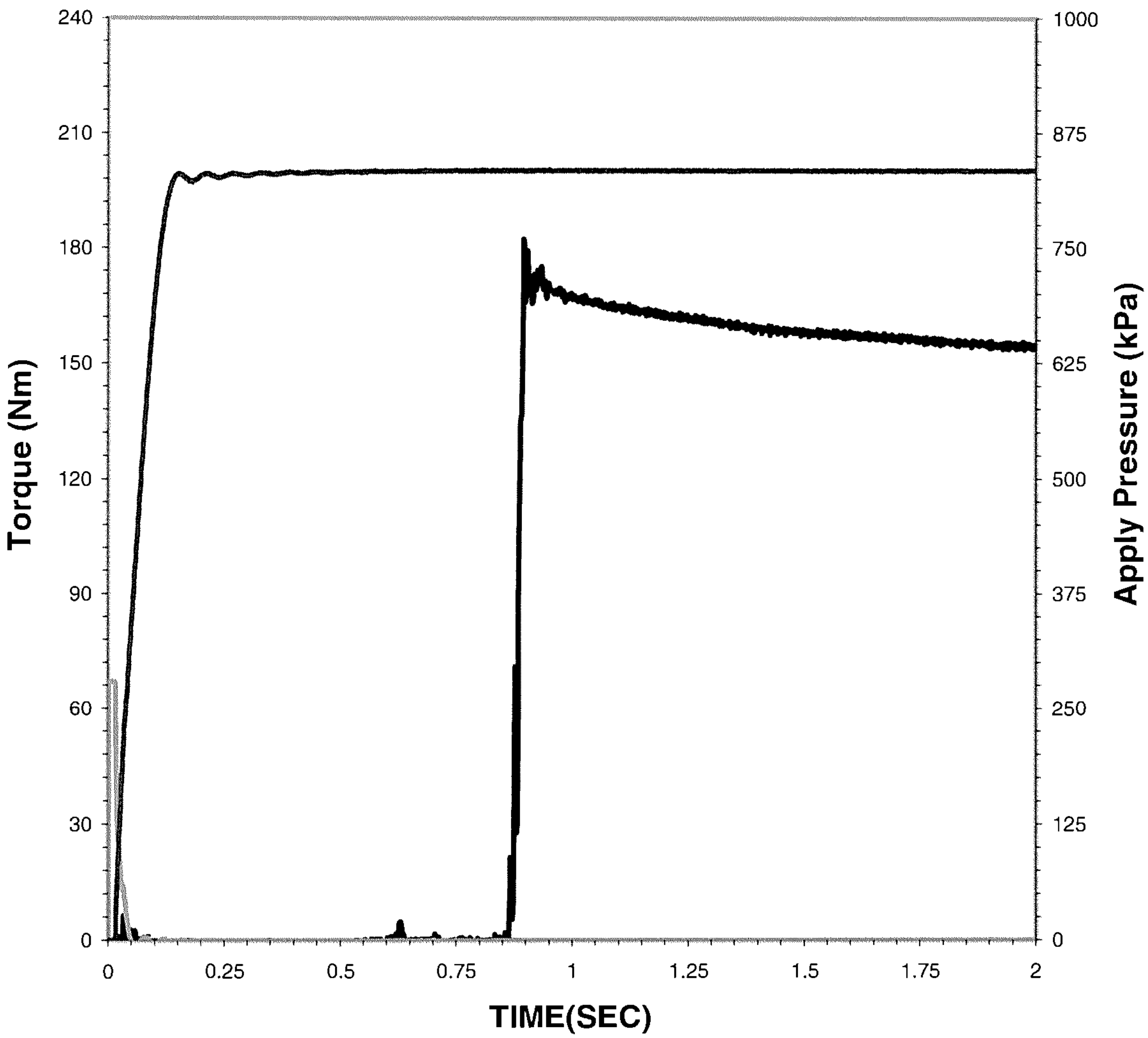
Apply Pressure:
At .25 Second: 830 kPa

Torque
Static Peak: 193 Nm
.25 Second: 168 Nm

Coefficient of Friction
Static Peak: 0.133
.25 Second: 0.116

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 12:56:18

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 5000

PHASE B

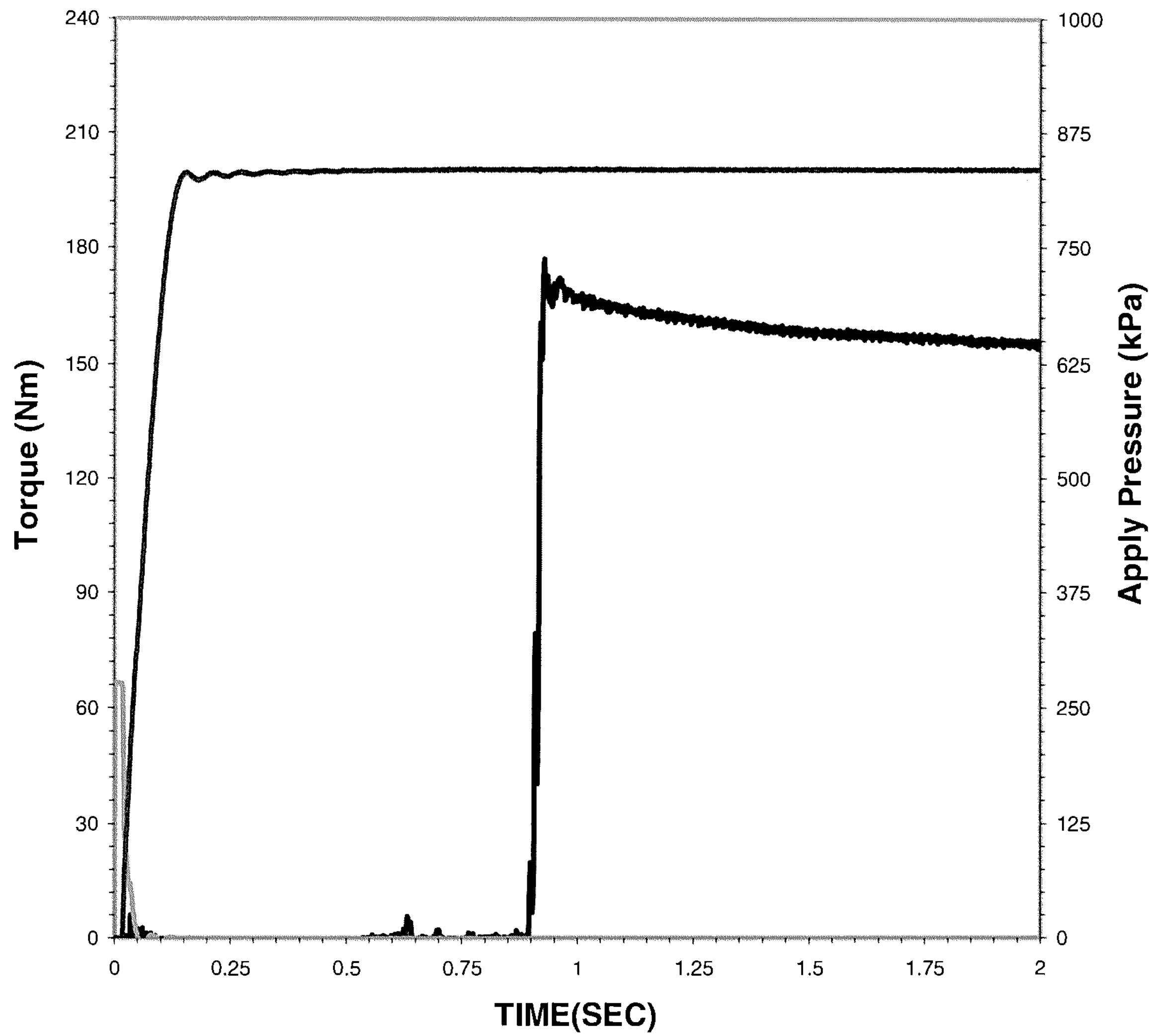
Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 183 Nm
.25 Second: 165 Nm

Coefficient of Friction
Static Peak: 0.126
.25 Second: 0.114

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 15:01:30

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 5500

PHASE B

Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 177 Nm
.25 Second: 163 Nm

Coefficient of Friction
Static Peak: 0.123
.25 Second: 0.113

APPENDIX – D1 (Part 2)
TYPE C-4 PAPER CLUTCH FRICTION TEST
LO-268869

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

Allison Heavy-Duty Transmission Fluid
TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted for

ARMY LAB

Oil Code:
LO268869

Test Number:
C2-3-1573

October 15, 2011

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluid Evaluations

IX. Paper Clutch Friction Test

Test Laboratory: SWRI
Test Number: C2-3-1573
Friction Plate Batch: LOT 6
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-268869
Sponsor Fluid Code: LO268869
Completion Date: 10/15/11

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0970	0.0903

	Before	After
Pack Clearance	0.9144	1.1684

Reference Tests

Test Number	Test Date	Test Fluid
C2-0-1557	08/12/10	RDL-2746 08-05
C2-0-1568	12/10/10	RDL-2746 08-05
C2-0-1570	01/13/11	RDL-2746 08-05

	New	EOT
Viscosity at 40°C, cSt	47.67	41.55
Viscosity at 100°C, cSt	8.78	7.86
Iron Content, ppm	2	139

D5185	New Fluid (ppm)
Ba	<1
B	<1
Ca	3439
Mg	10
P	1279
Si	2
Na	5
Zn	1879

Name: Matthew Jackson
Title: Manager

Signature: [signature]
Date: 10/24/11

ALLISON C- 4 PAPER FRICTION TEST

(Torque in N*m)

Sponsor Fluid Code: **LO268869**	Test Number: **C2-3-1573**
Lab Fluid Code: **LO-268869**	Fric. Plate Batch: **LOT 6**
Completion Date: **10/15/2011**	Steel Plate Batch: **10/9/2008**

TORQUE

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.53	190	212	22	210	196
500	0.52	198	201	3	195	189
1000	0.49	209	258	49	271	260
2500	0.46	223	286	63	306	280
5000	0.45	231	255	24	272	249
7500	0.46	227	235	8	251	229
10000	0.46	227	228	1	236	227

COEFFICIENT OF FRICTION

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.53	0.093	0.103	0.010	0.102	0.095
500	0.52	0.096	0.098	0.002	0.095	0.092
1000	0.49	0.102	0.126	0.024	0.132	0.127
2500	0.46	0.109	0.139	0.030	0.149	0.136
5000	0.45	0.112	0.124	0.012	0.132	0.121
7500	0.46	0.111	0.114	0.003	0.122	0.112
10000	0.46	0.111	0.111	0.000	0.115	0.111

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.530	0.460	-13.21	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.093	0.111	19.35	F
Static Friction Coeff.	N/A	N/A	0.103	0.111	7.77	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.102	0.115	12.75	
0.25 Second Low Speed Coeff.	N/A	N/A	0.095	0.111	16.84	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-PAPER FRICTION TEST

(all units in mm)

Candidate Fluid: LO268869 | **Test Number : C2-3-1573** | **Completion Date : 10/15/2011**

Lab Fluid Code : LO-268869 | **Steel Plate Batch: 10/09/2008** | **Fric Plate Batch : LOT 6**

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.0740	1.9810	2.0660	1.9690	0.0930		0.0970
	120	2.0760	1.9850	2.0690	1.9810	0.0910		0.0880
	240	2.0760	1.9820	2.0730	1.9820	0.0940		0.0910
	Average					0.0927	0.0923	0.0920
5	Top	2.0780	1.9920	2.0760	1.9930	0.0860		0.0830
	120	2.0700	1.9770	2.0620	1.9730	0.0930		0.0890
	240	2.0800	1.9910	2.0780	1.9890	0.0890		0.0890
	Average					0.0893	0.0882	0.0870
STEELS SEPARATORS								
1	Top	1.7500	1.7500	1.7500	1.7500	0.0000		0.0000
	120	1.7500	1.7500	1.7500	1.7500	0.0000		0.0000
	240	1.7500	1.7500	1.7500	1.7500	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7580	1.7580	1.7590	1.7590	0.0000		0.0000
	120	1.7560	1.7560	1.7560	1.7560	0.0000		0.0000
	240	1.7590	1.7590	1.7590	1.7590	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
4	Top	1.7580	1.7580	1.7570	1.7570	0.0000		0.0000
	120	1.7540	1.7540	1.7540	1.7540	0.0000		0.0000
	240	1.7570	1.7570	1.7580	1.7580	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
6	Top	1.7560	1.7560	1.7560	1.7560	0.0000		0.0000
	120	1.7570	1.7570	1.7570	1.7570	0.0000		0.0000
	240	1.7590	1.7590	1.7590	1.7590	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T.: STEEL PLATES NO UNUSUAL DISCOLORATION
(Anything Unusual) NORMAL WEAR

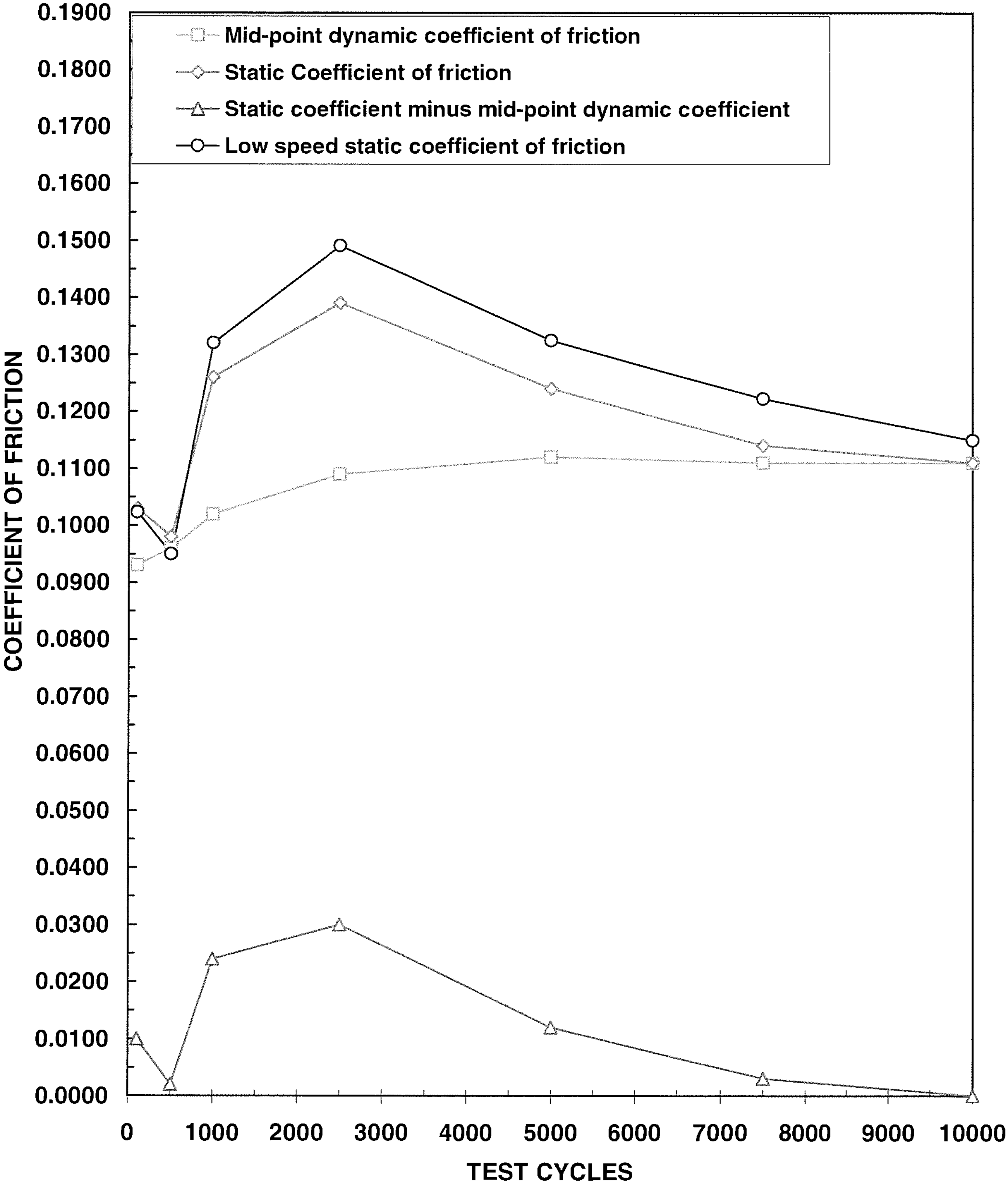
Test Date and Operator's Name: 9/28/2011 JOE M

Reviewed By (Signature and Date) 10/24/11

Pack ID#: 4658

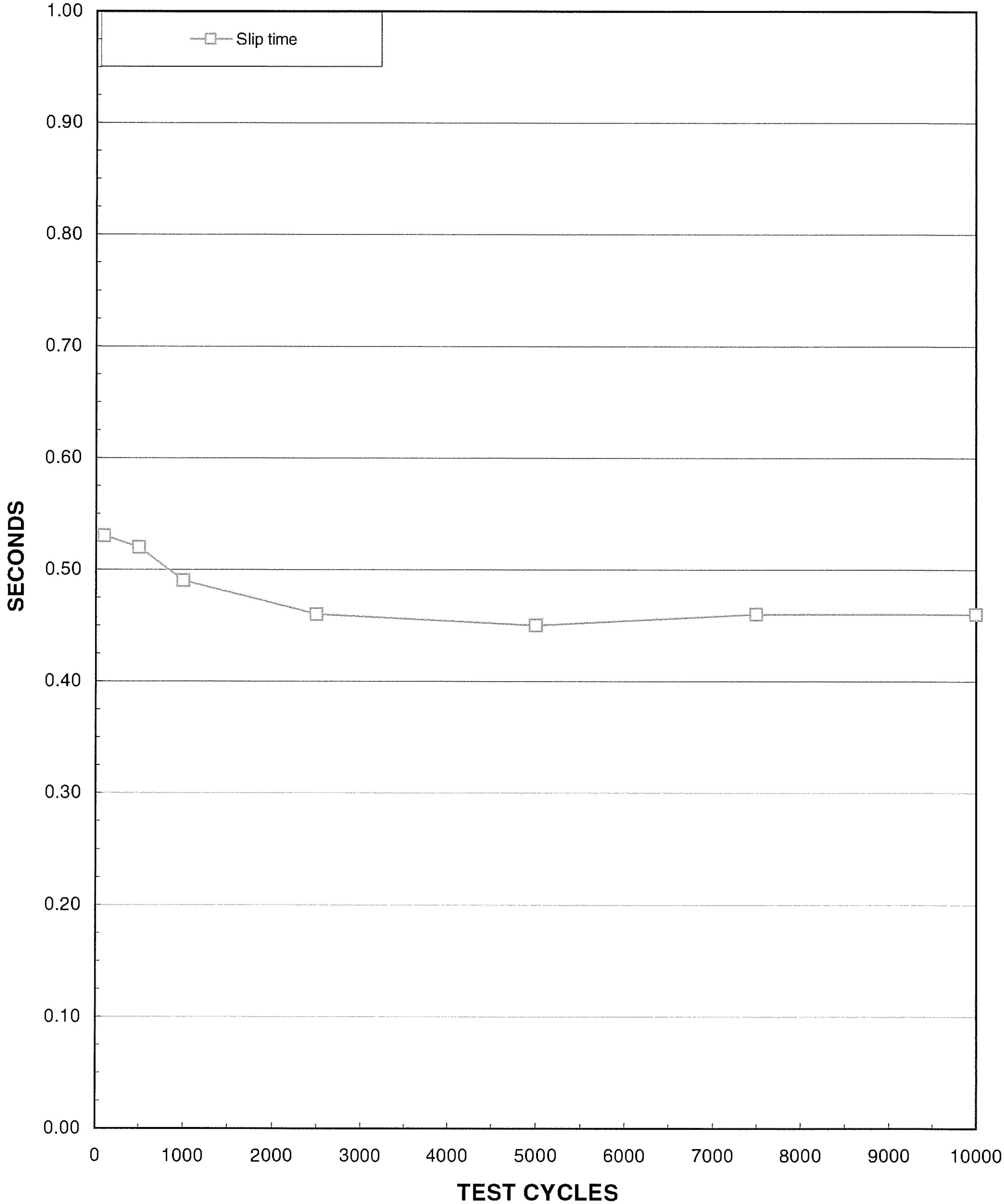
ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST

Fluid Code: LO268869 Test Number: C2-3-1573



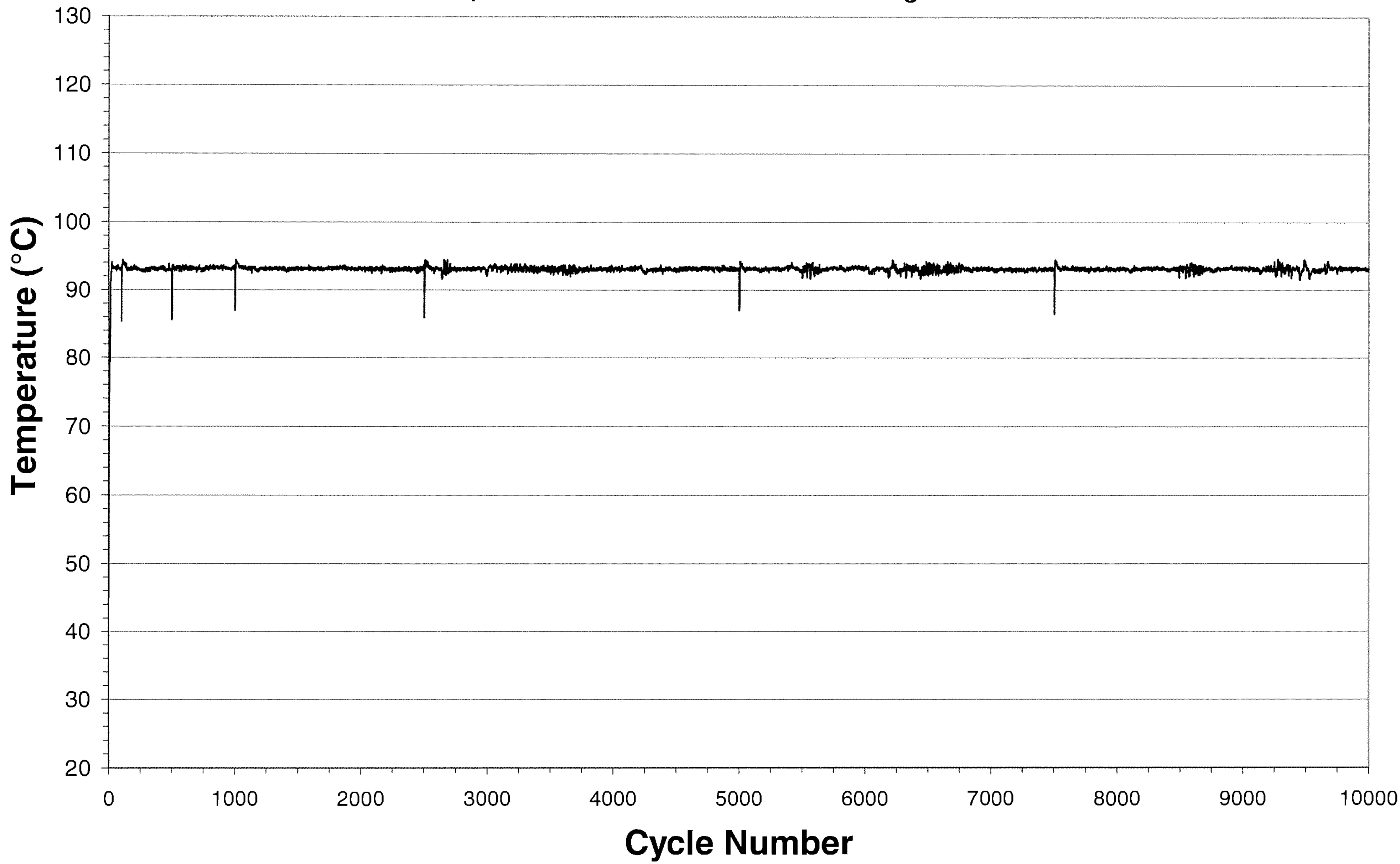
ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST

Fluid Code: LO268869 **Test Number: C2-3-1573**



C2-3-1573 LO268869

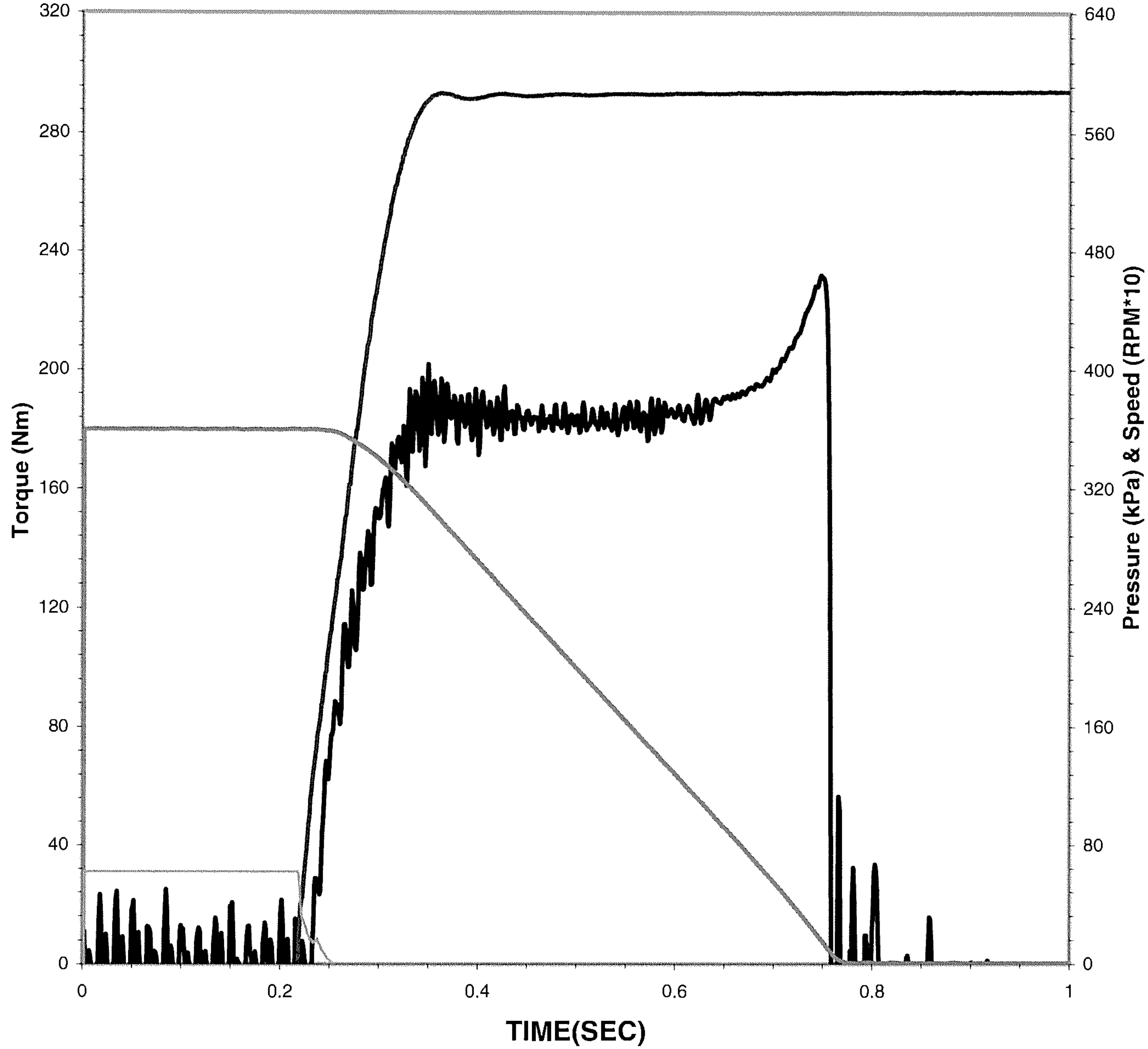
Temp: Max=94.6°C Min=45.0°C Avg=93.1°C



DYNAMIC TRACES

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/13/2011
Time of Test:	14:55:08
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	10
Temperature:	84.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.3 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.54 Sec

Torque

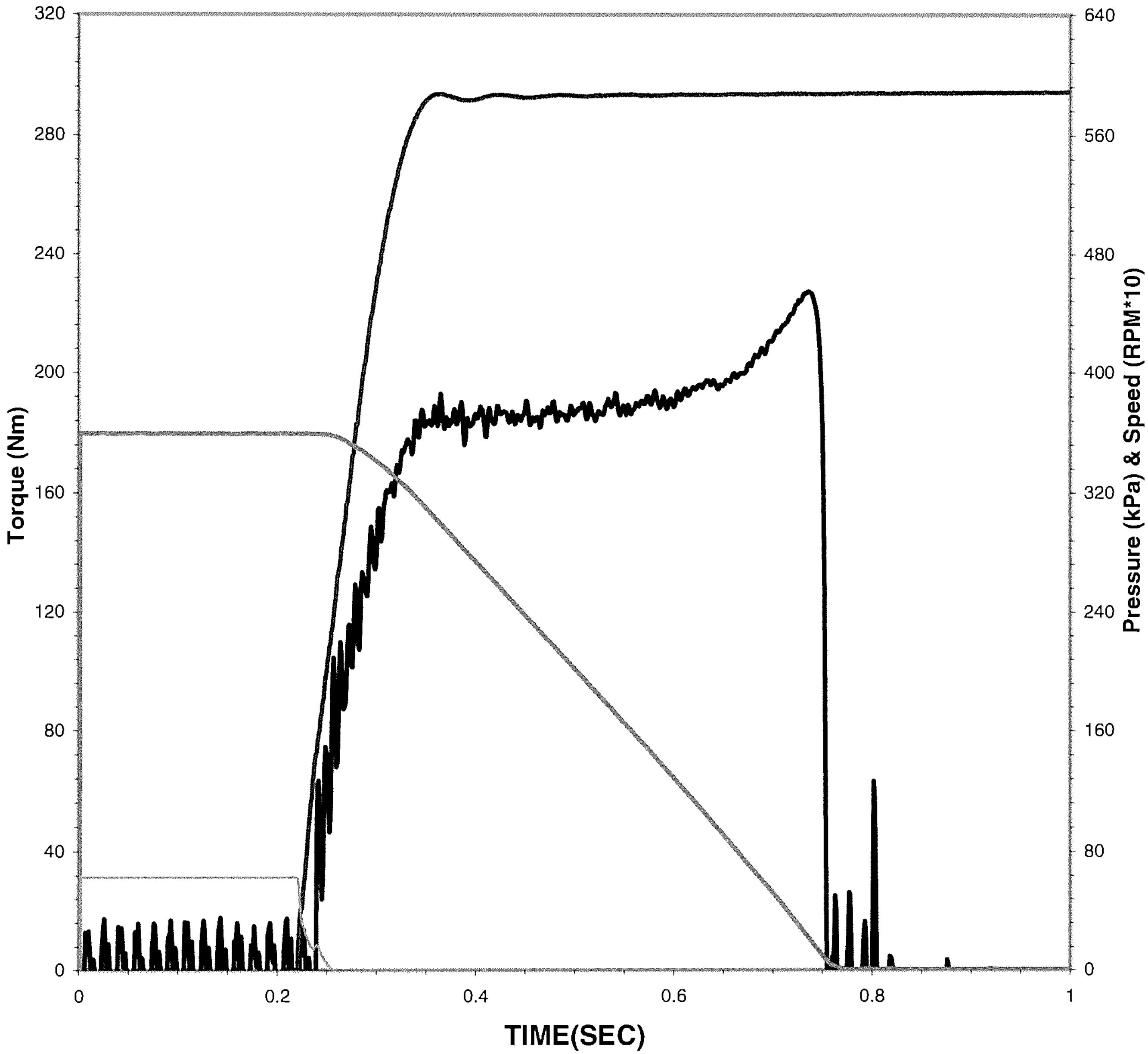
0.2 Sec Dyn:	189 N*m
Midpoint Dyn:	187 N*m
LwSpd Dynamic:	223 N*m

Coefficient of Friction

.2 Sec Dyn:	0.092
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.109

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/13/2011
Time of Test:	15:17:39
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	99
Temperature:	93.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.534 Sec

Torque

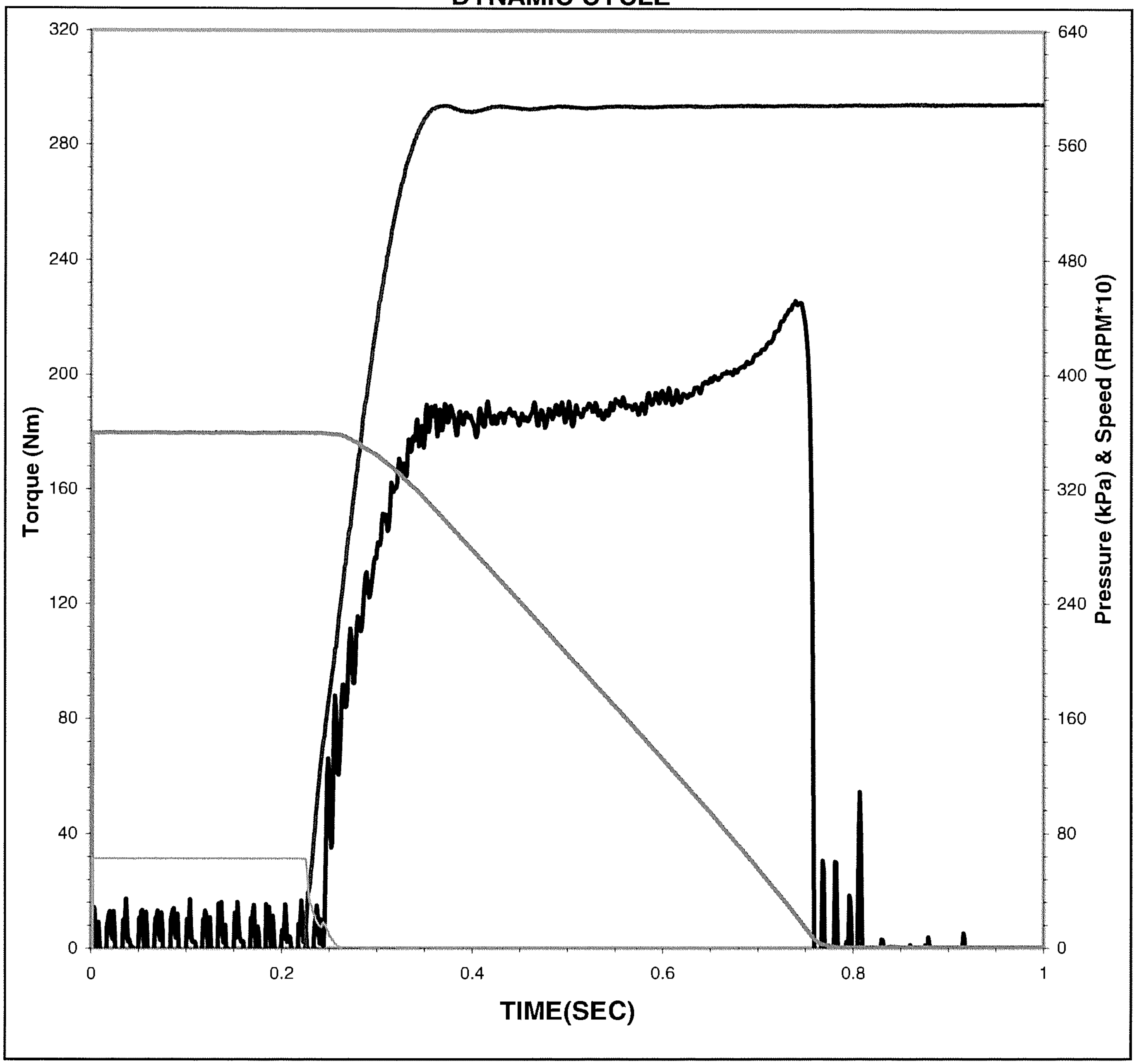
0.2 Sec Dyn:	190 N*m
Midpoint Dyn:	190 N*m
LwSpd Dynamic:	213 N*m

Coefficient of Friction

.2 Sec Dyn:	0.092
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.103

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/13/2011
Time of Test:	15:17:55
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	100
Temperature:	93.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.3 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.533 Sec

Torque

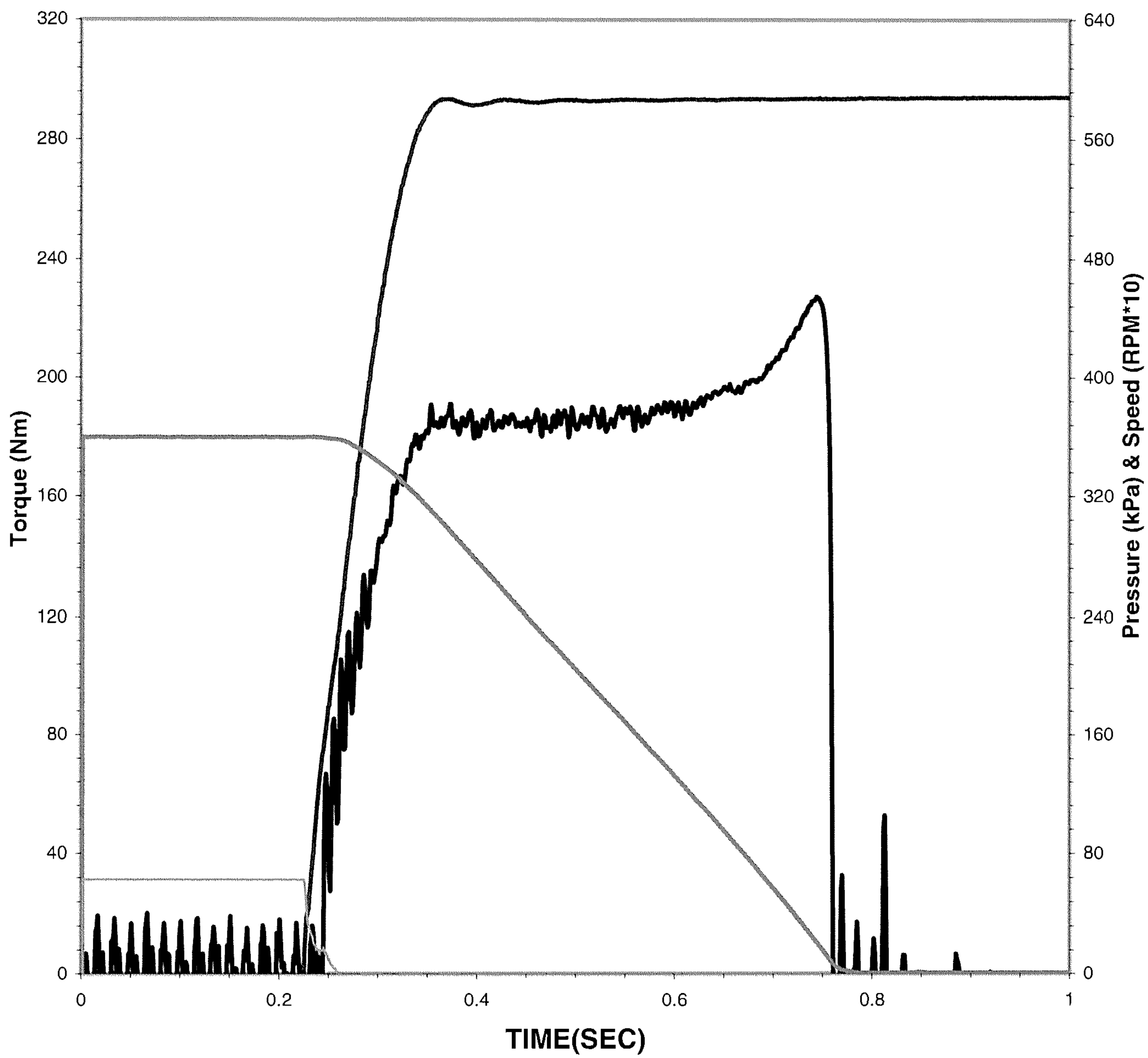
0.2 Sec Dyn:	189 N*m
Midpoint Dyn:	190 N*m
LwSpd Dynamic:	210 N*m

Coefficient of Friction

.2 Sec Dyn:	0.092
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.102

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/13/2011
Time of Test:	15:18:26
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	101
Temperature:	85.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.3 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.535 Sec

Torque

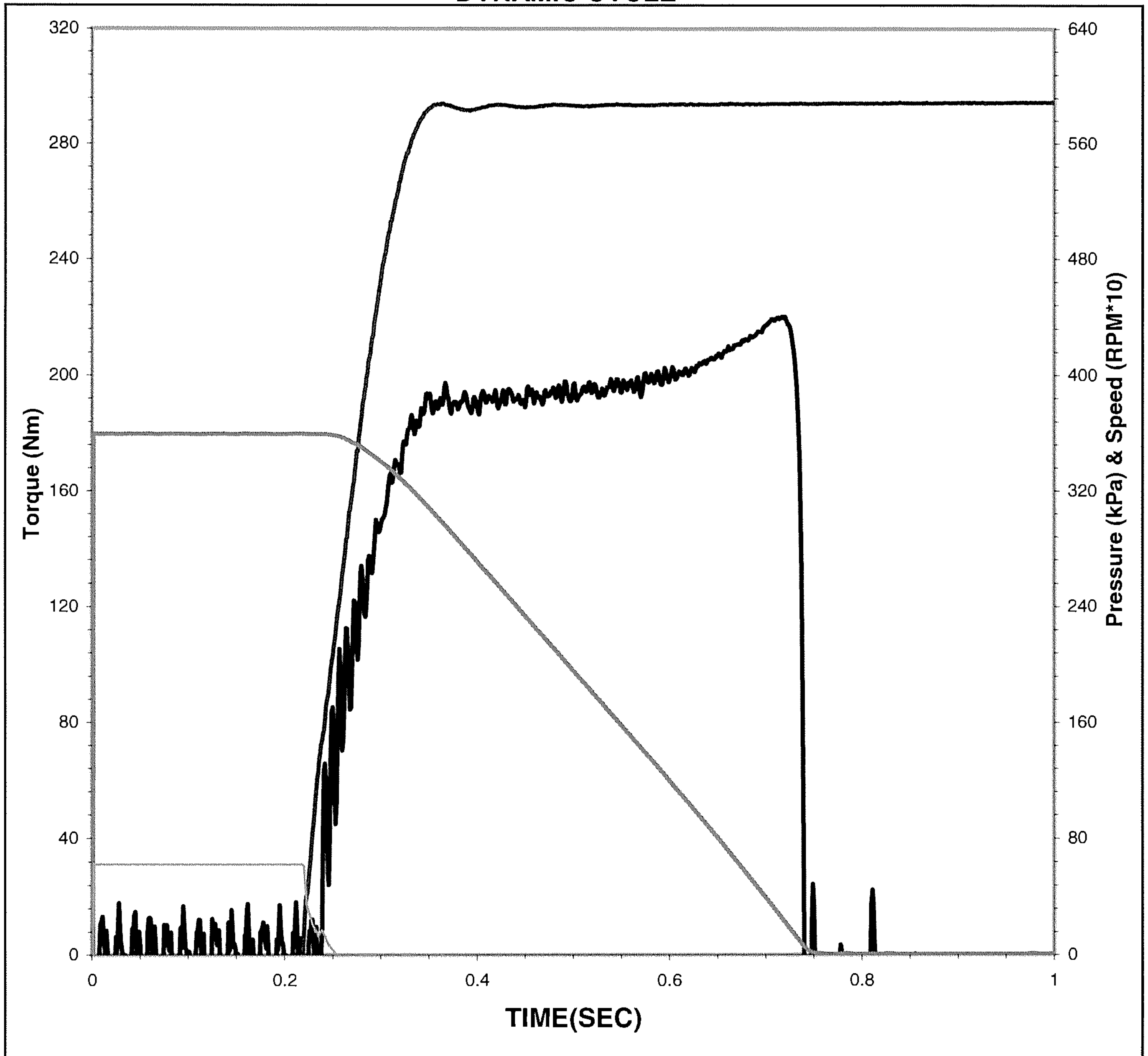
0.2 Sec Dyn:	189 N*m
Midpoint Dyn:	189 N*m
LwSpd Dynamic:	214 N*m

Coefficient of Friction

.2 Sec Dyn:	0.092
Midpoint Dyn:	0.092
LwSpd Dynamic:	0.104

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 10/13/2011

Time of Test: 16:57:56

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 499

Temperature: 92.7 °C (93.3 ± 3.0 °C)

Apply Pressure: 588 kPa (586 ± 7 KPa)

Apply Rate: 0.13 Sec (0.15 ± 0.02 Sec)

Energy: 18.4 KJ (18.7 ± 0.40 KJ)

Engage Time: 0.52 Sec

Torque

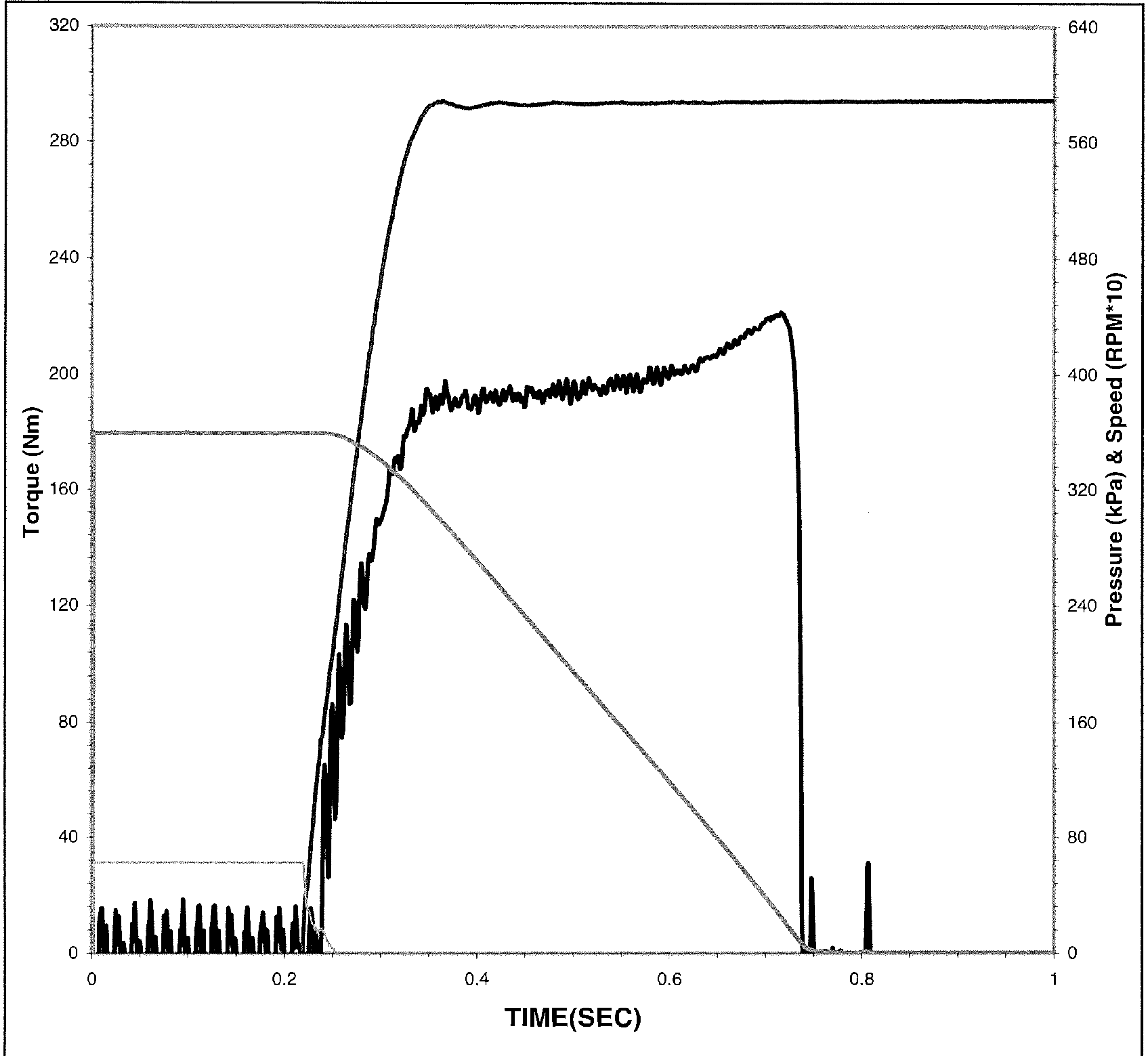
0.2 Sec Dyn:	196 N*m
Midpoint Dyn:	198 N*m
LwSpd Dynamic:	201 N*m

Coefficient of Friction

.2 Sec Dyn:	0.096
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.098

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 10/13/2011

Time of Test: 16:58:11

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 500

Temperature: 92.7 °C
(93.3 ± 3.0 °C)

Apply Pressure: 588 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.519 Sec

Torque

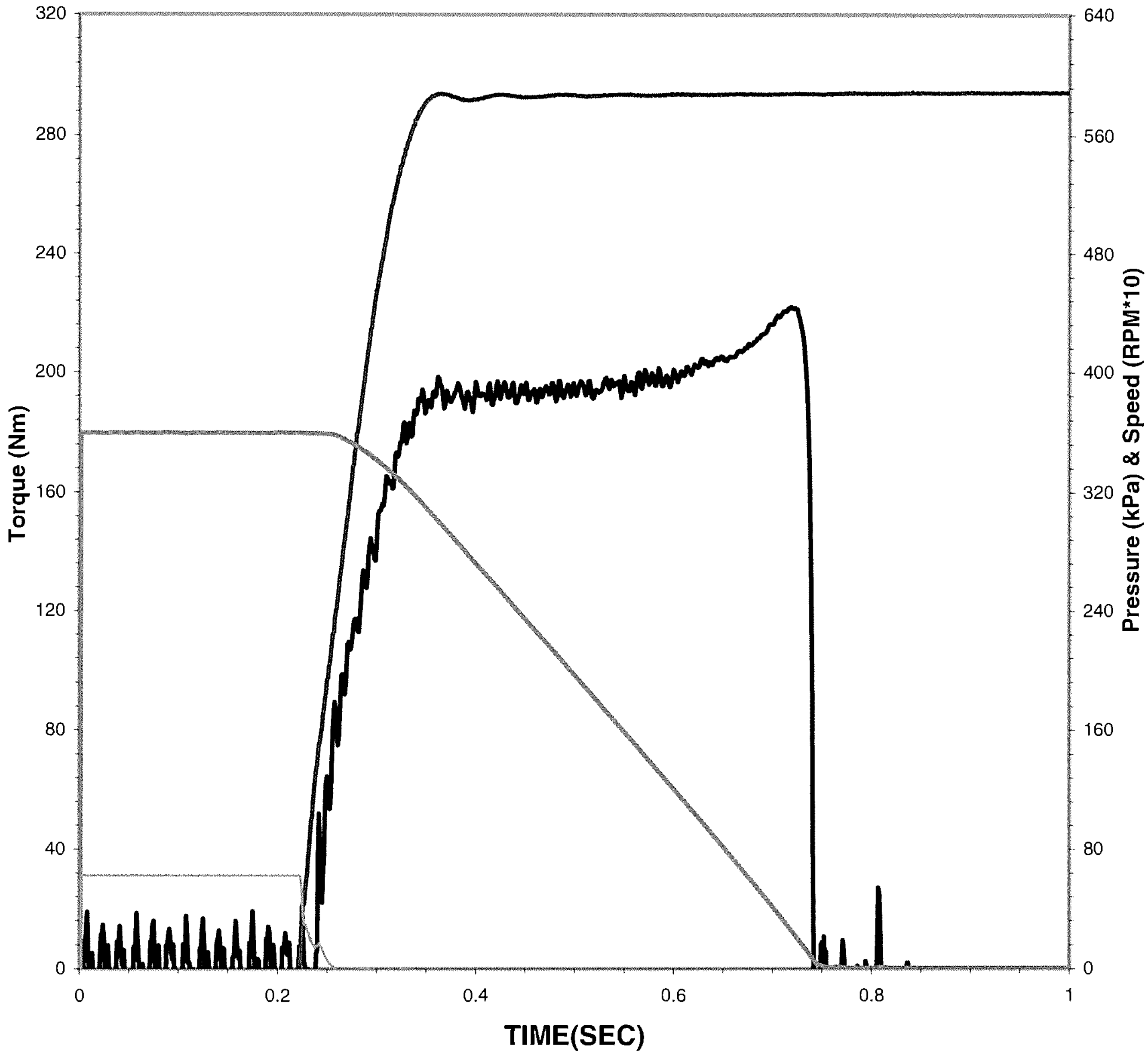
0.2 Sec Dyn: 197 N*m
Midpoint Dyn: 198 N*m
LwSpd Dynamic: 198 N*m

Coefficient of Friction

.2 Sec Dyn: 0.096
Midpoint Dyn: 0.097
LwSpd Dynamic: 0.096

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/13/2011
Time of Test:	16:58:42
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	501
Temperature:	85.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.3 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.519 Sec

Torque

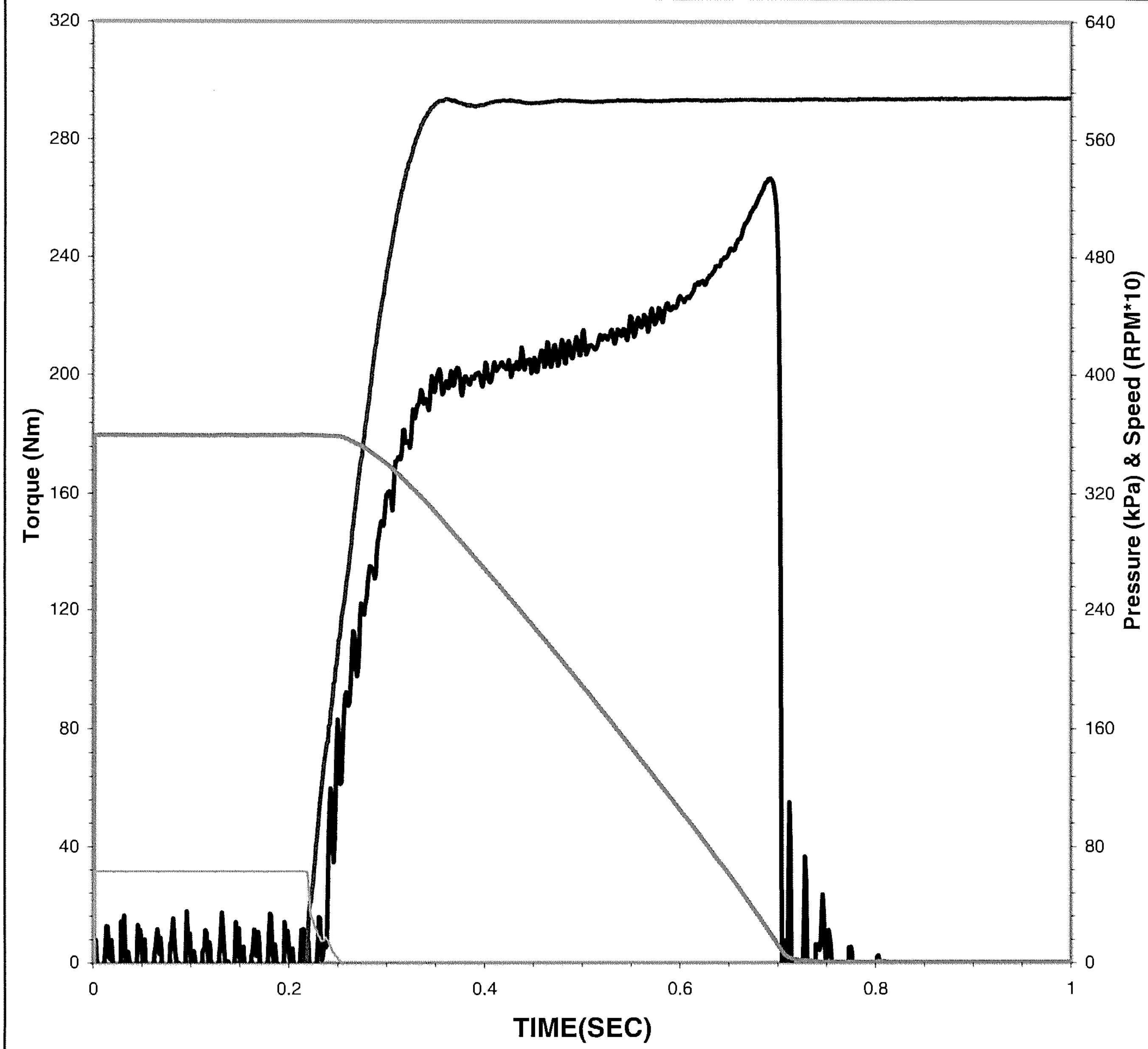
0.2 Sec Dyn:	198 N*m
Midpoint Dyn:	198 N*m
LwSpd Dynamic:	204 N*m

Coefficient of Friction

.2 Sec Dyn:	0.096
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.099

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/13/2011
Time of Test:	19:03:12
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	999
Temperature:	93.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	587 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.486 Sec

Torque

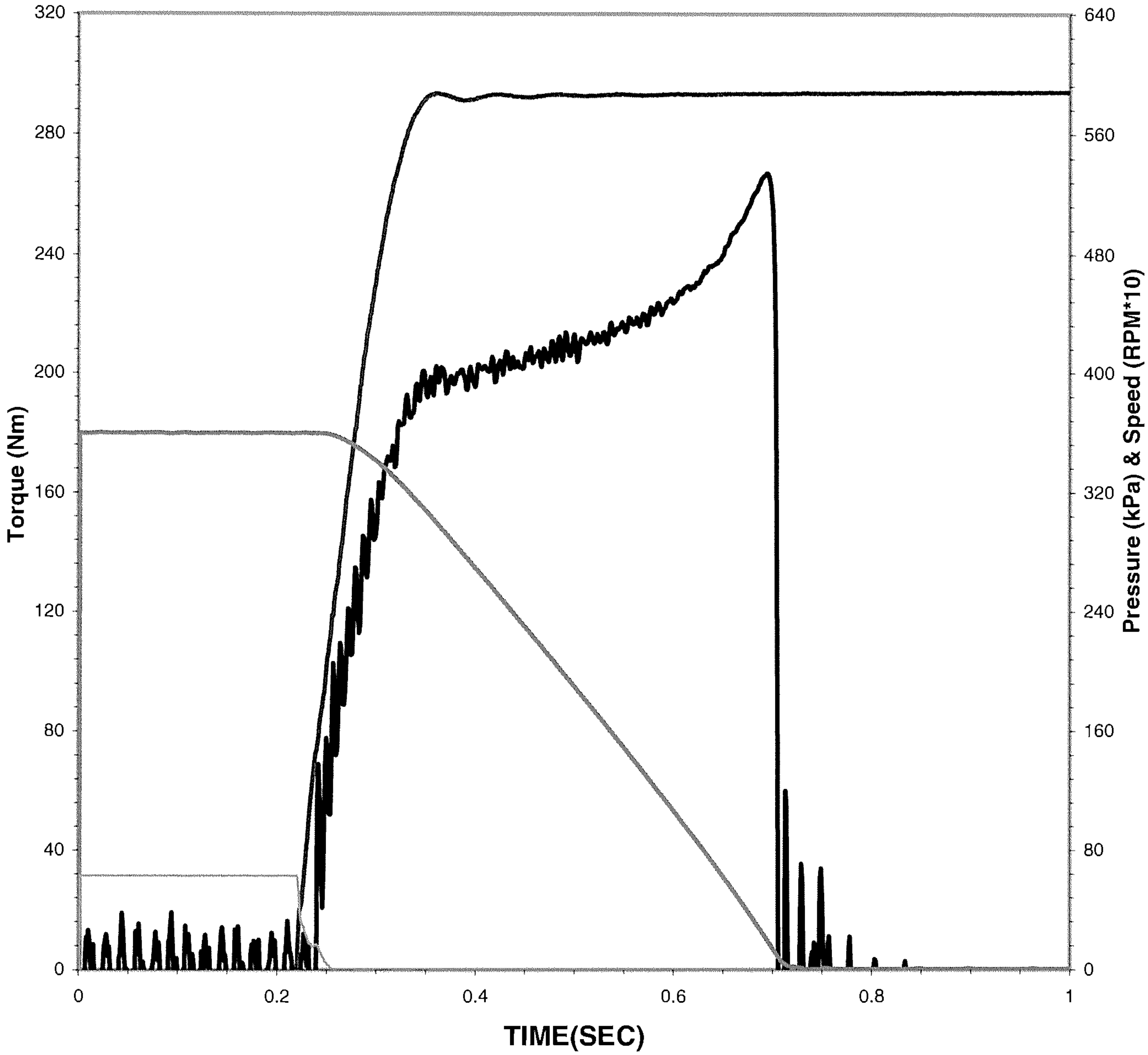
0.2 Sec Dyn:	207 N*m
Midpoint Dyn:	210 N*m
LwSpd Dynamic:	256 N*m

Coefficient of Friction

.2 Sec Dyn:	0.101
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.124

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/13/2011
Time of Test:	19:03:27
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	1000
Temperature:	93.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	587 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.485 Sec

Torque

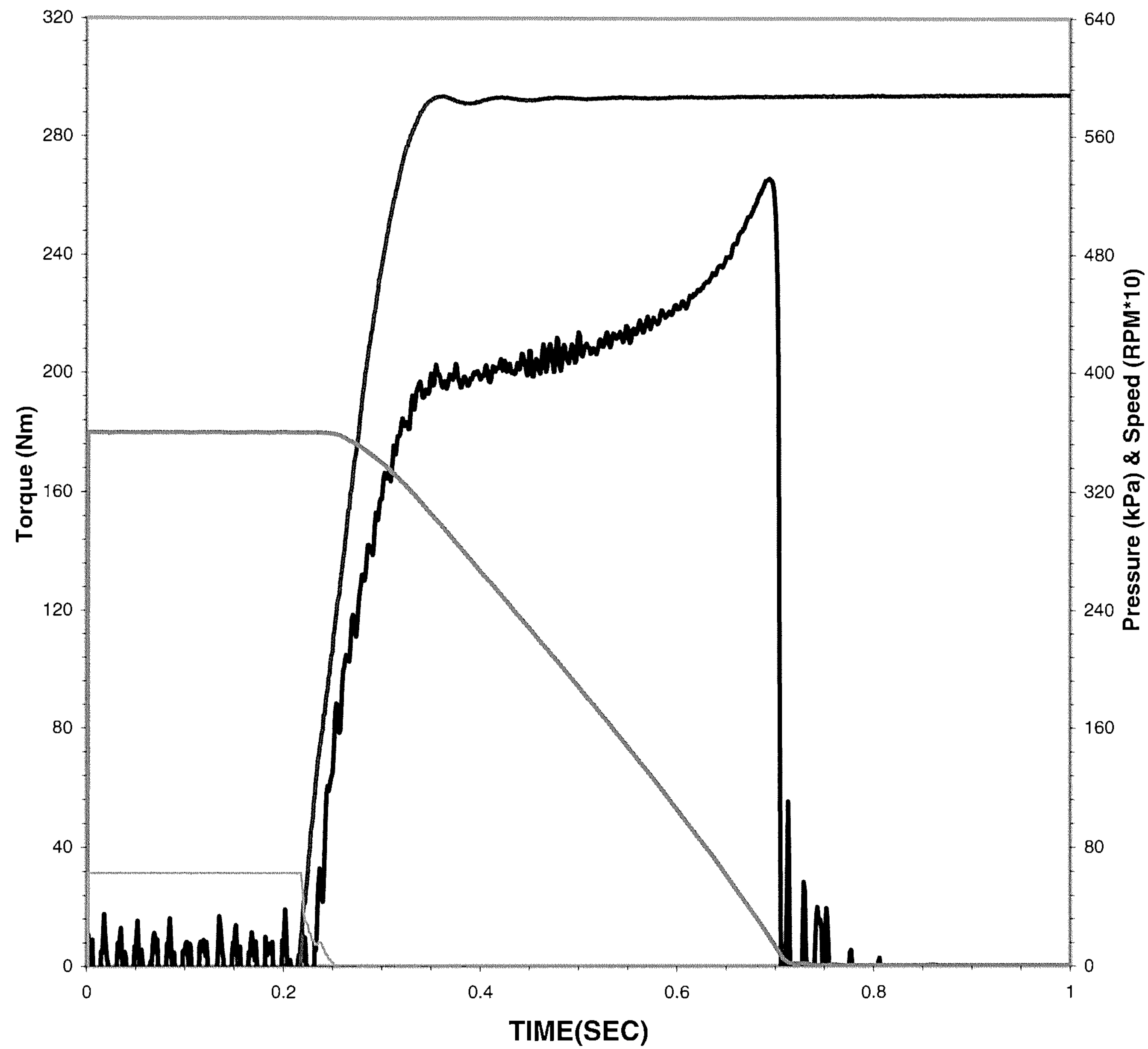
0.2 Sec Dyn:	206 N*m
Midpoint Dyn:	210 N*m
LwSpd Dynamic:	260 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.126

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/13/2011
Time of Test:	19:03:58
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	1001
Temperature:	87.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	587 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.488 Sec

Torque

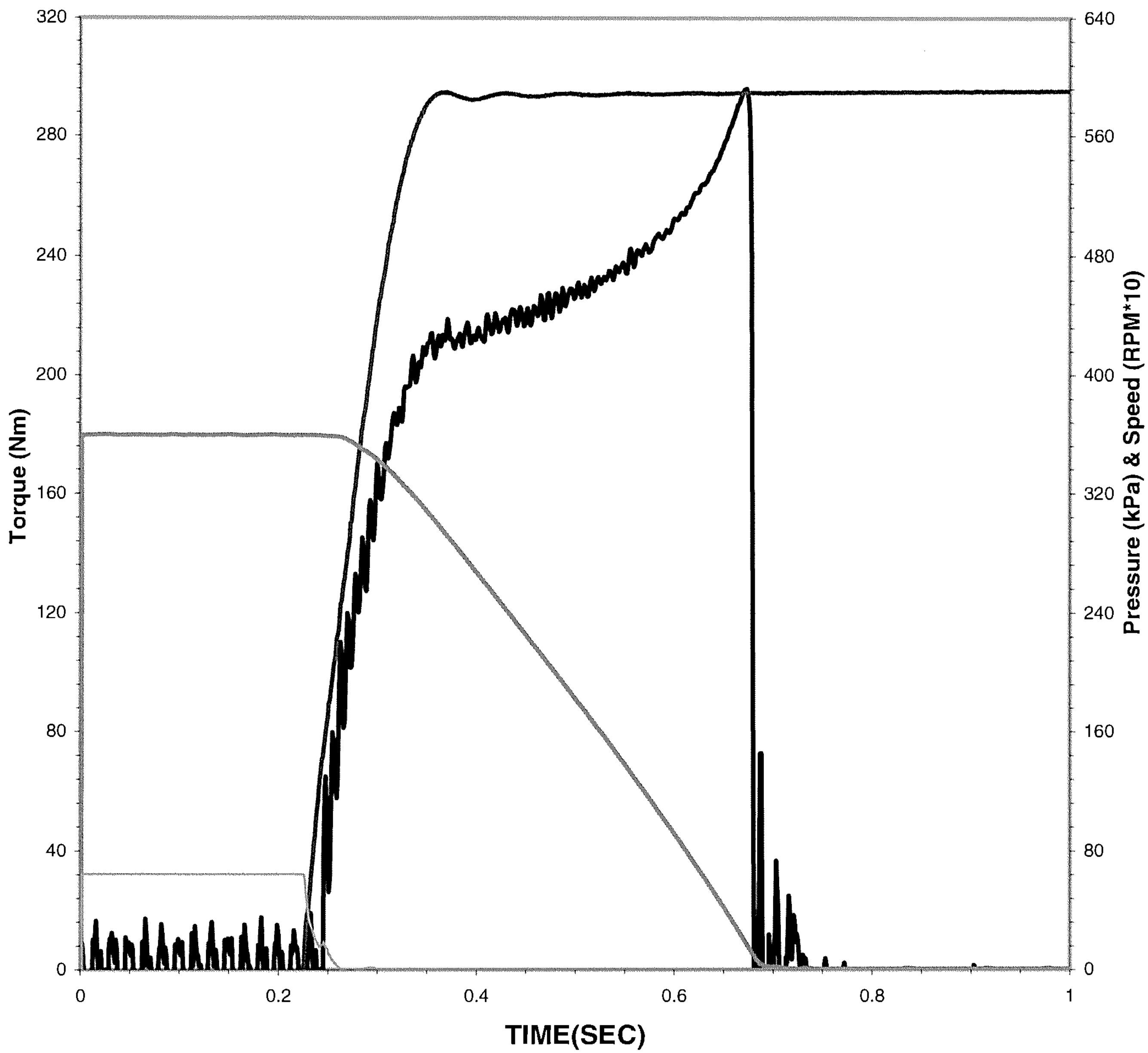
0.2 Sec Dyn:	206 N*m
Midpoint Dyn:	208 N*m
LwSpd Dynamic:	258 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.101
LwSpd Dynamic:	0.126

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/14/2011
Time of Test:	1:18:28
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	2499
Temperature:	93.3 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	589 kPa
	(586 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.5 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.454 Sec

Torque

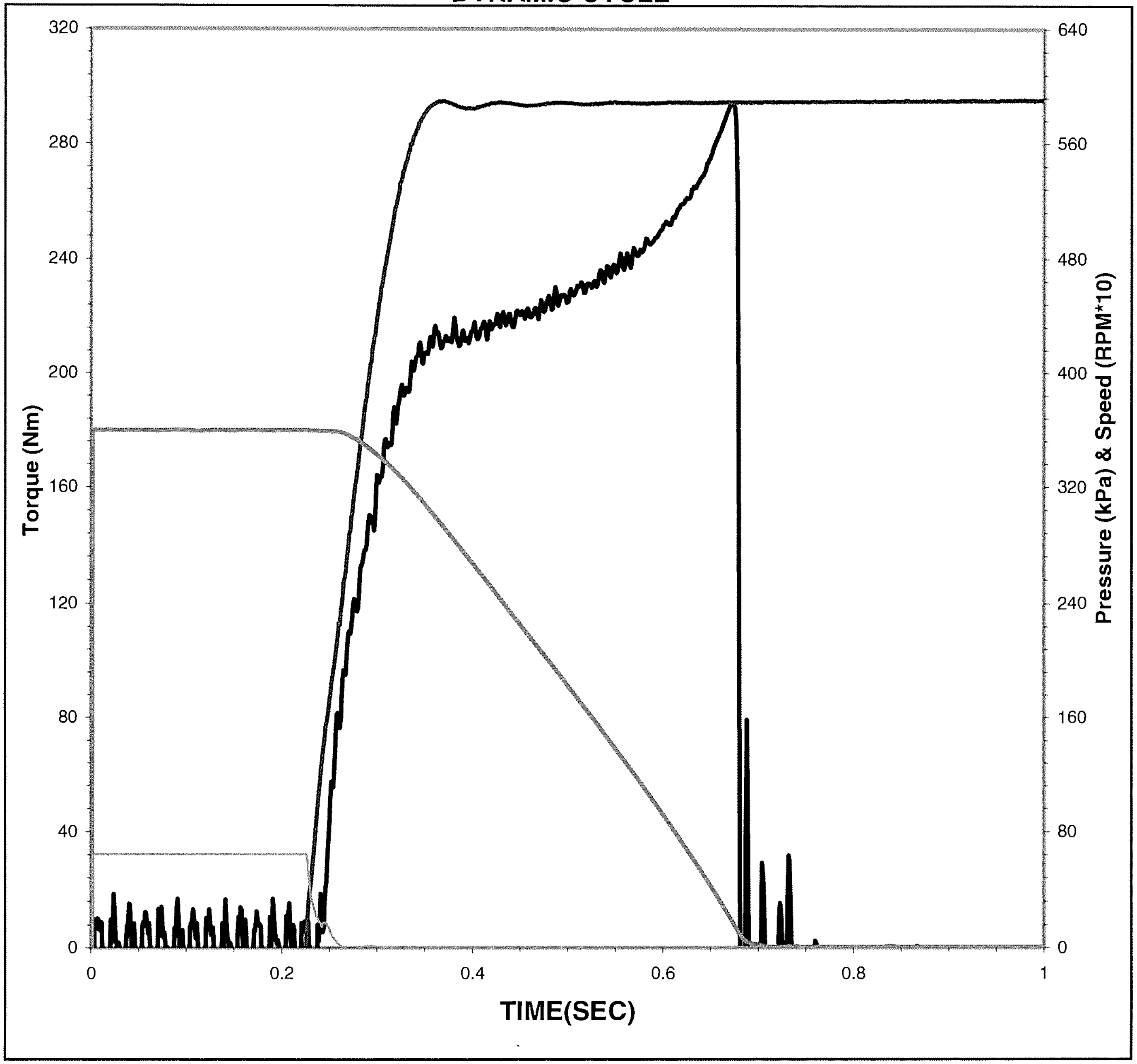
0.2 Sec Dyn:	221 N*m
Midpoint Dyn:	224 N*m
LwSpd Dynamic:	291 N*m

Coefficient of Friction

.2 Sec Dyn:	0.108
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.141

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/14/2011
Time of Test:	1:18:43
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	2500
Temperature:	93.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.454 Sec

Torque

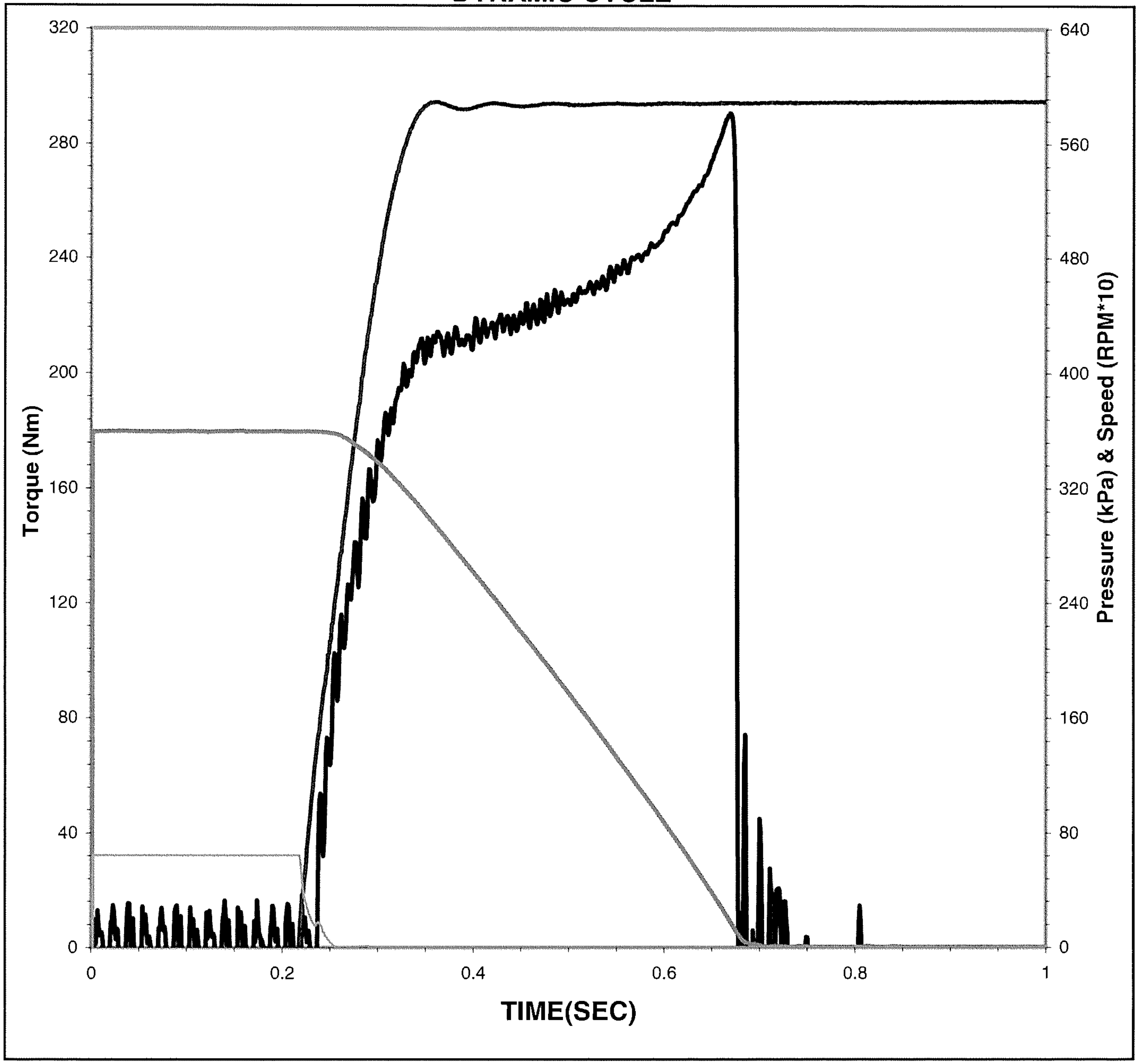
0.2 Sec Dyn:	222 N*m
Midpoint Dyn:	224 N*m
LwSpd Dynamic:	285 N*m

Coefficient of Friction

.2 Sec Dyn:	0.108
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.139

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/14/2011
Time of Test:	1:19:15
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	2501
Temperature:	85.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.459 Sec

Torque

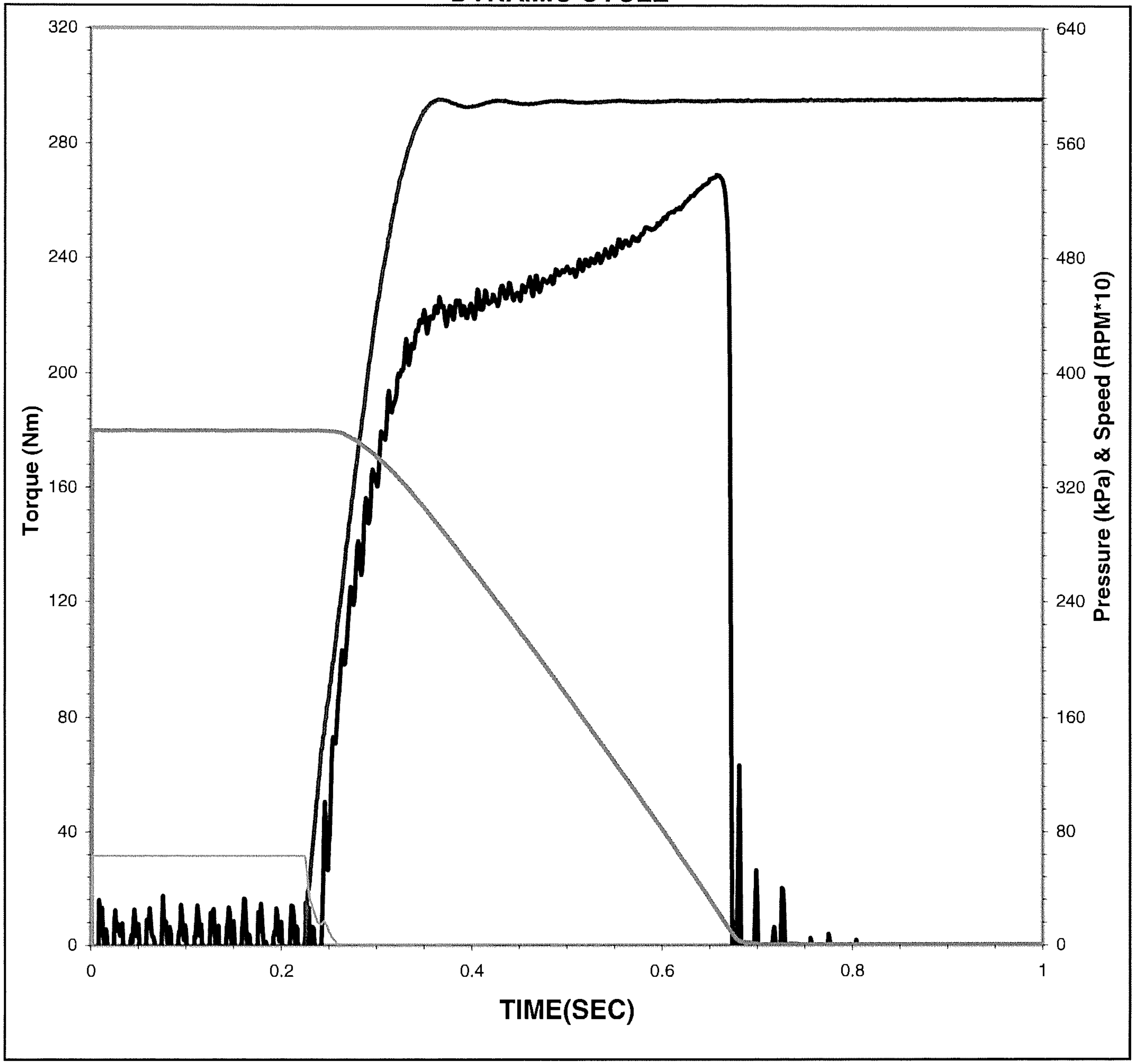
0.2 Sec Dyn:	219 N*m
Midpoint Dyn:	222 N*m
LwSpd Dynamic:	283 N*m

Coefficient of Friction

.2 Sec Dyn:	0.107
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.138

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/14/2011
Time of Test:	11:42:34
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	4999
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.448 Sec

Torque

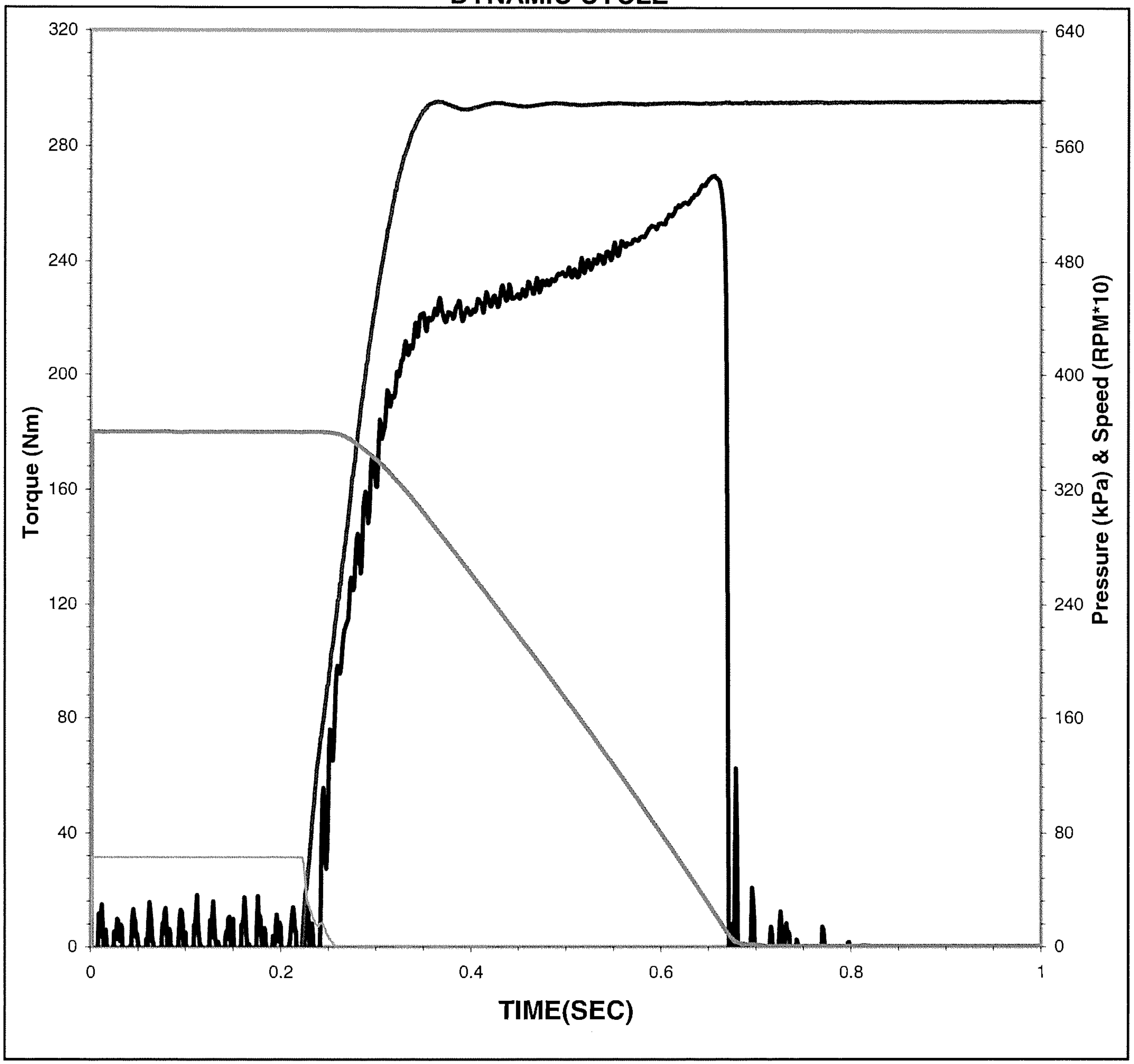
0.2 Sec Dyn:	230 N*m
Midpoint Dyn:	232 N*m
LwSpd Dynamic:	257 N*m

Coefficient of Friction

.2 Sec Dyn:	0.112
Midpoint Dyn:	0.113
LwSpd Dynamic:	0.125

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/14/2011
Time of Test:	11:42:49
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	5000
Temperature:	92.8 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.448 Sec

Torque

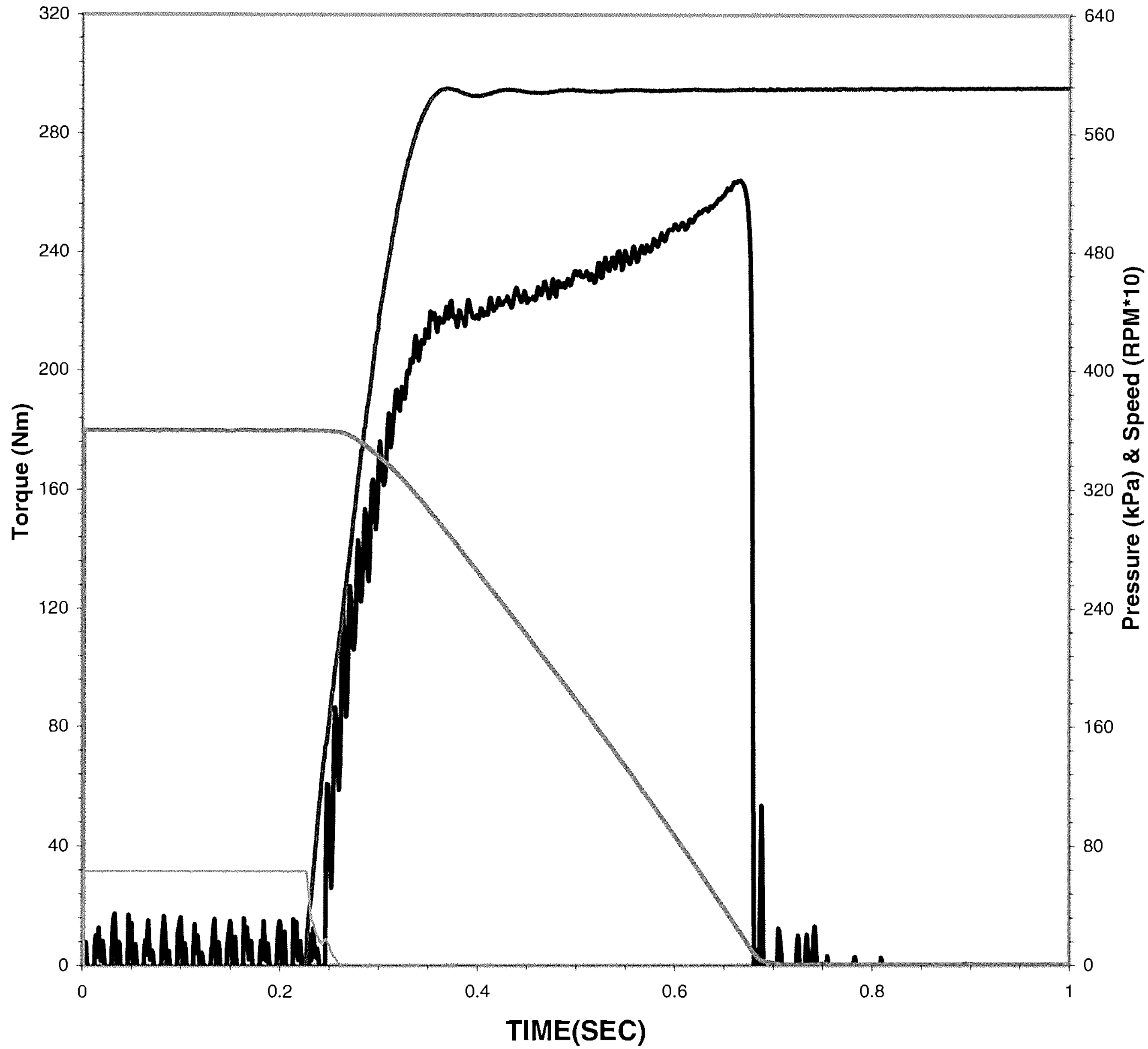
0.2 Sec Dyn:	230 N*m
Midpoint Dyn:	232 N*m
LwSpd Dynamic:	257 N*m

Coefficient of Friction

.2 Sec Dyn:	0.112
Midpoint Dyn:	0.113
LwSpd Dynamic:	0.125

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 10/14/2011

Time of Test: 11:43:20

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 5001

Temperature: 87.0 °C
(93.3 ± 3.0 °C)
Apply Pressure: 590 kPa
(586 ± 7 KPa)
Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)
Energy: 18.5 KJ
(18.7 ± 0.40 KJ)
Engage Time: 0.453 Sec

Torque

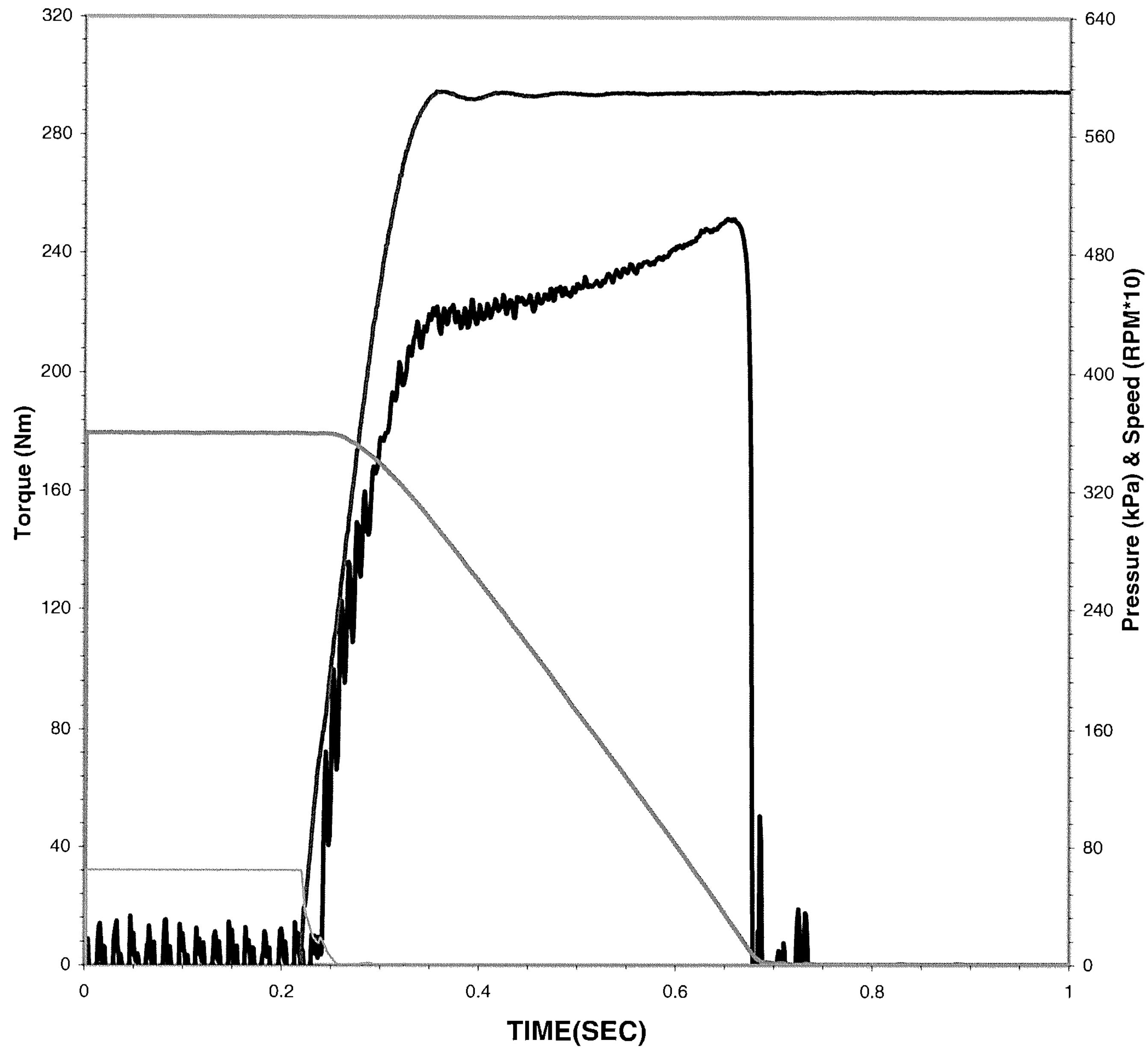
0.2 Sec Dyn: 227 N*m
Midpoint Dyn: 229 N*m
LwSpd Dynamic: 251 N*m

Coefficient of Friction

.2 Sec Dyn: 0.110
Midpoint Dyn: 0.112
LwSpd Dynamic: 0.122

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/14/2011
Time of Test:	22:07:50
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	7499
Temperature:	93.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.458 Sec

Torque

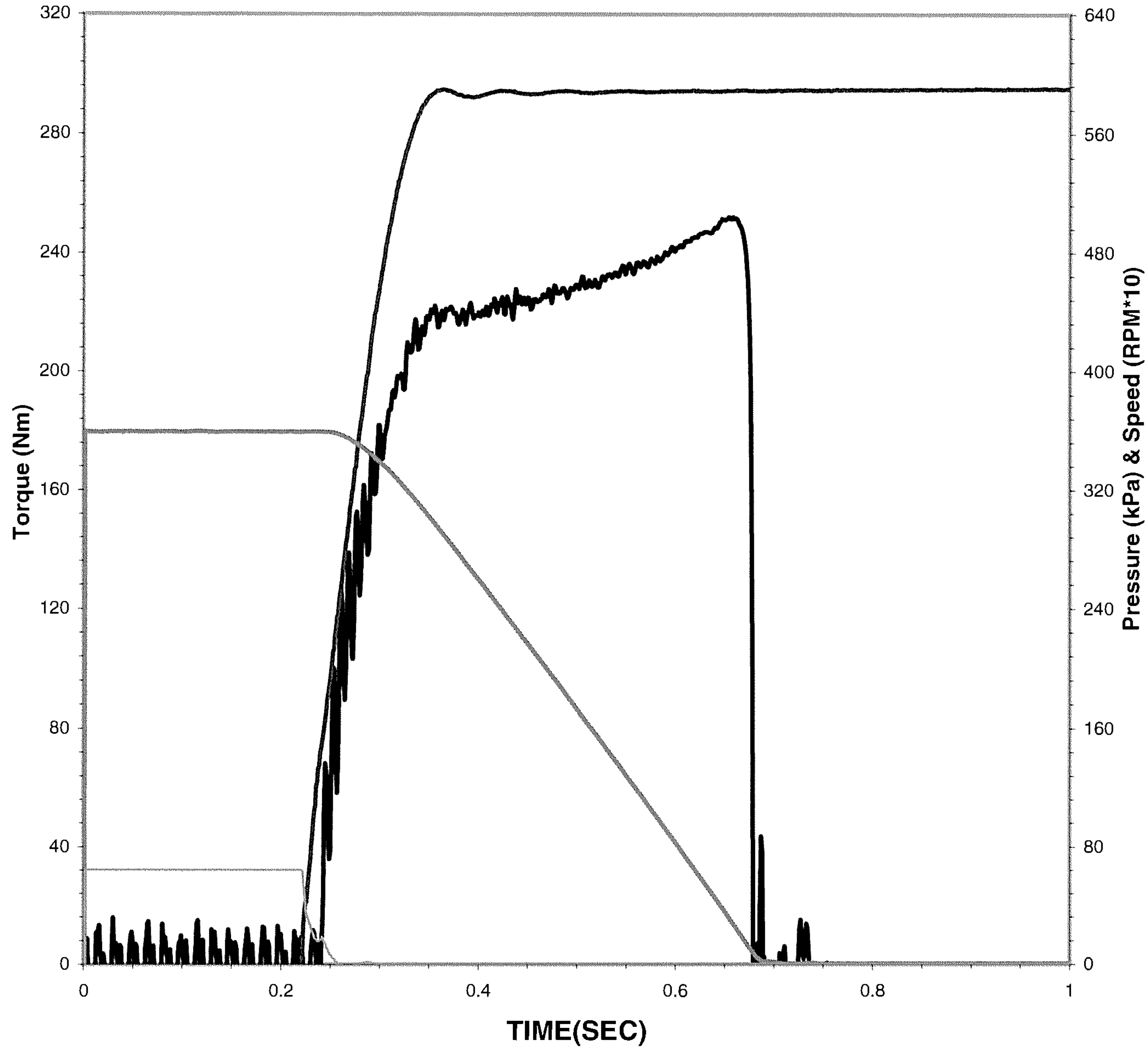
0.2 Sec Dyn:	227 N*m
Midpoint Dyn:	228 N*m
LwSpd Dynamic:	236 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.115

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/14/2011
Time of Test:	22:08:05
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	7500
Temperature:	93.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.457 Sec

Torque

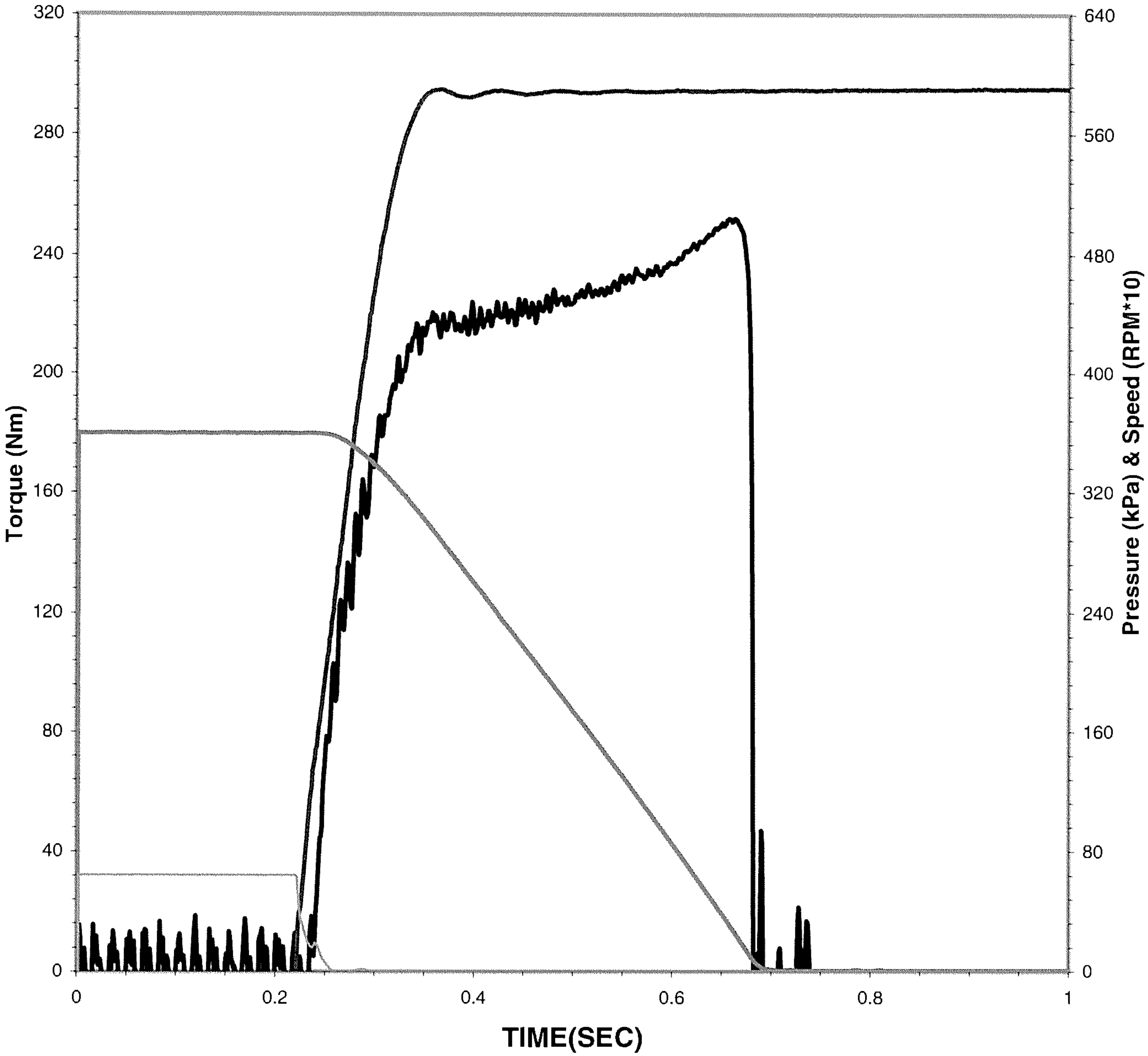
0.2 Sec Dyn:	227 N*m
Midpoint Dyn:	228 N*m
LwSpd Dynamic:	235 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.114

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/14/2011
Time of Test:	22:08:36
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	7501
Temperature:	**86.5 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**589 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.46 Sec**

Torque

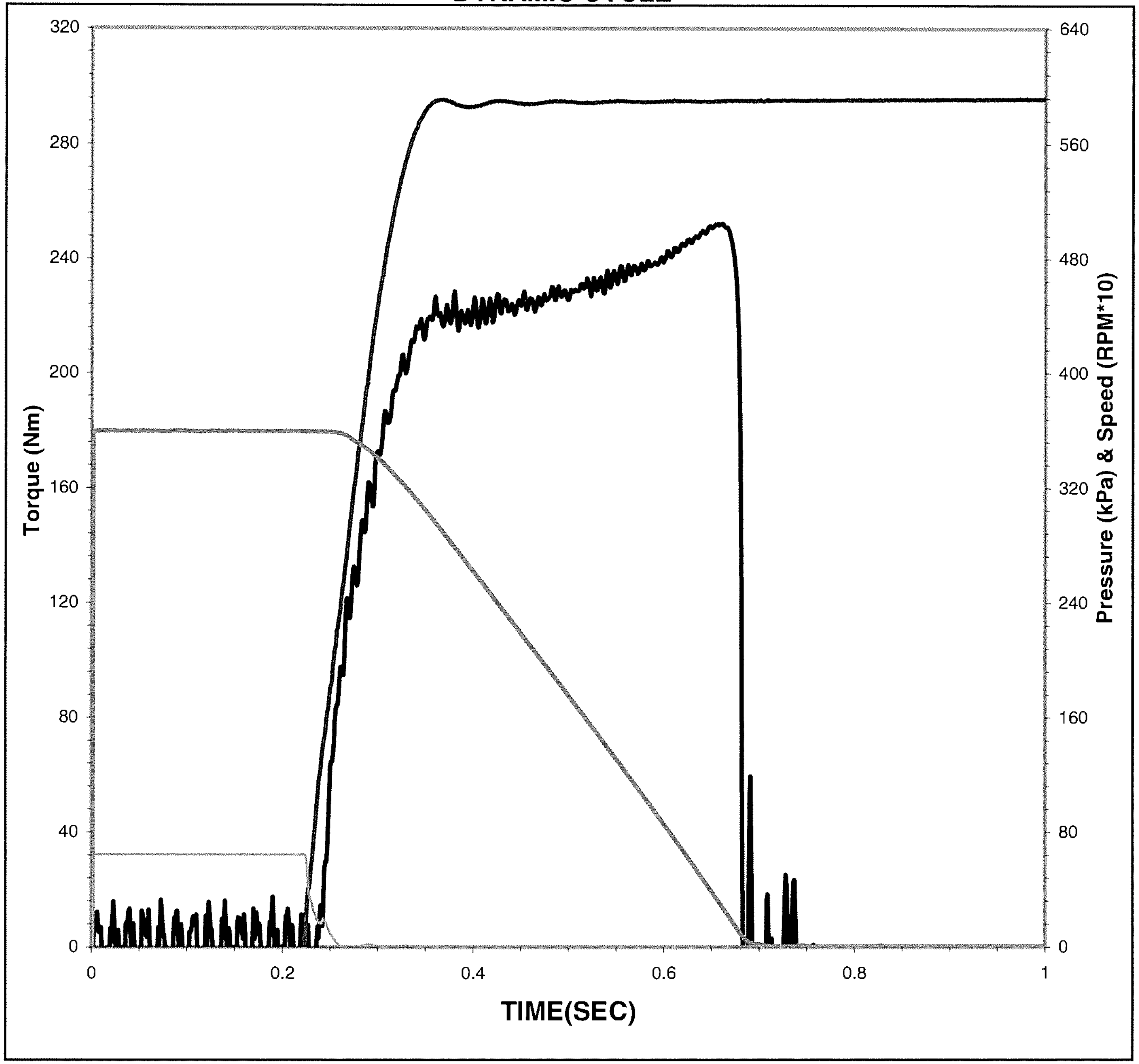
0.2 Sec Dyn:	224 N*m
Midpoint Dyn:	225 N*m
LwSpd Dynamic:	236 N*m

Coefficient of Friction

.2 Sec Dyn:	0.109
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.115

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	8:32:51
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	9998
Temperature:	93.1 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	590 kPa
	(586 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.5 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.458 Sec

Torque

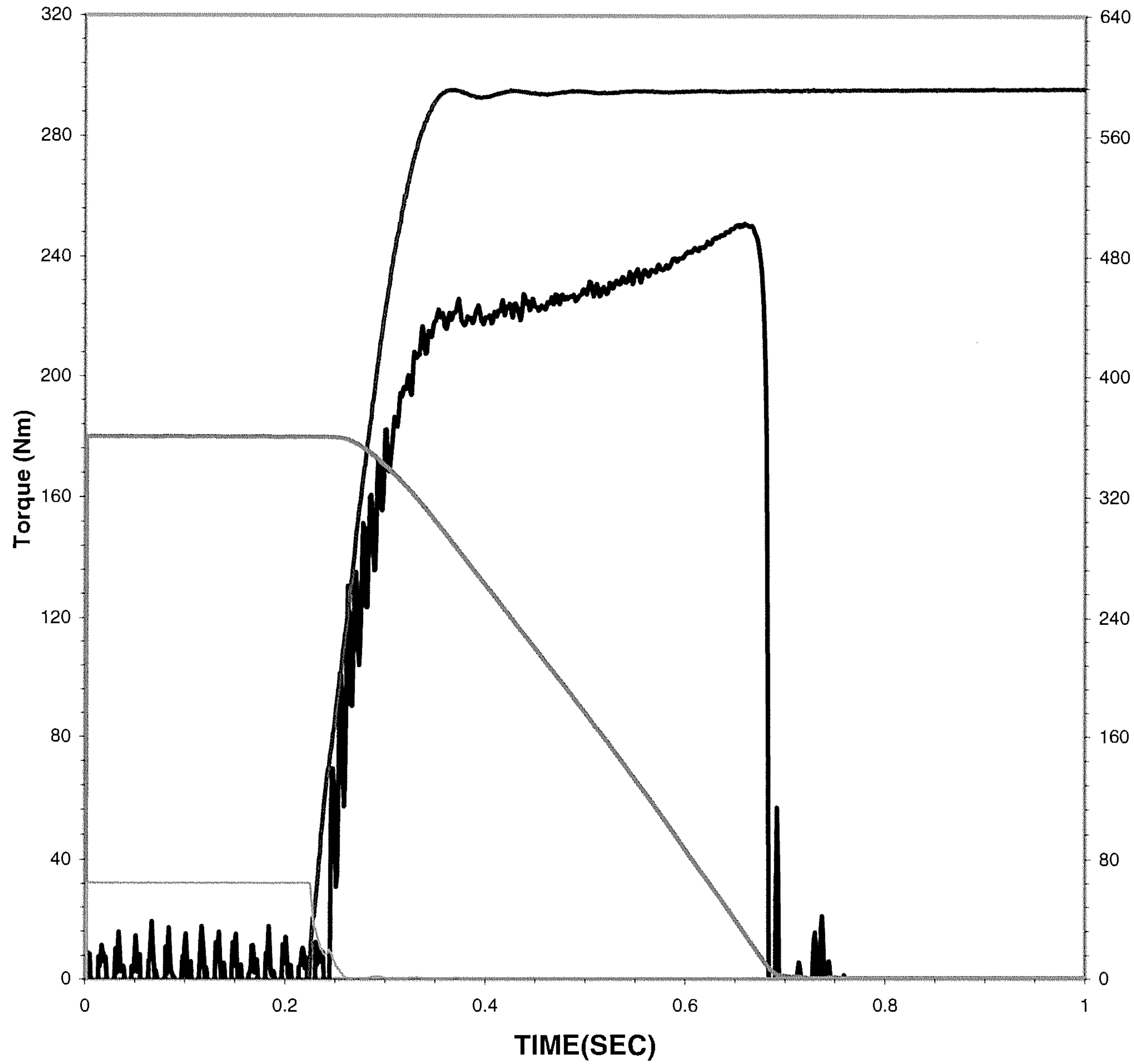
0.2 Sec Dyn:	227 N*m
Midpoint Dyn:	227 N*m
LwSpd Dynamic:	226 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.110

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	8:33:06
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	9999
Temperature:	93.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.458 Sec

Torque

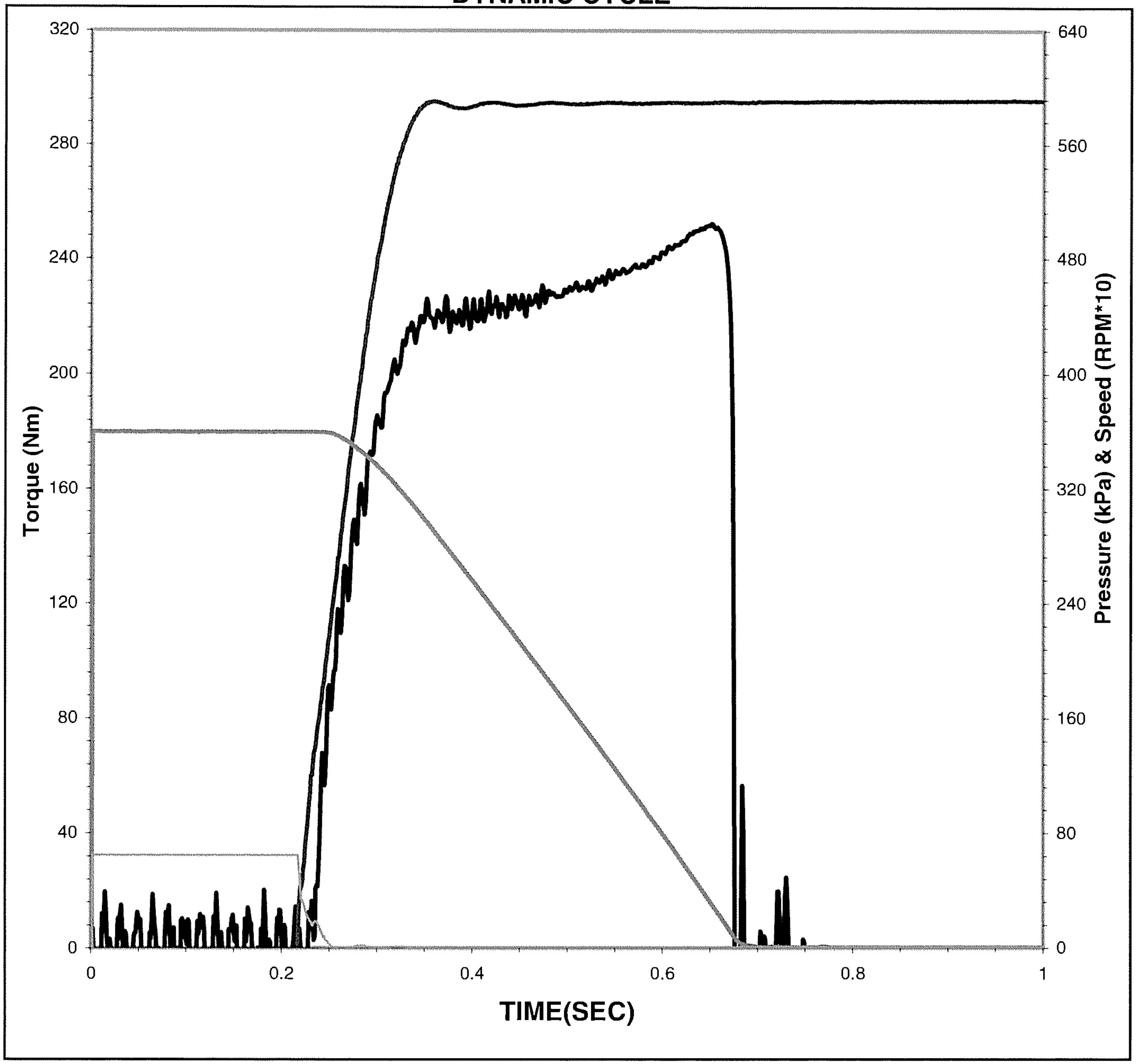
0.2 Sec Dyn:	225 N*m
Midpoint Dyn:	227 N*m
LwSpd Dynamic:	227 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.111

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	8:33:21
Test Number:	C2-3-1573
Fluid Code:	LO268869
Cycle Number:	10000
Temperature:	93.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.458 Sec

Torque

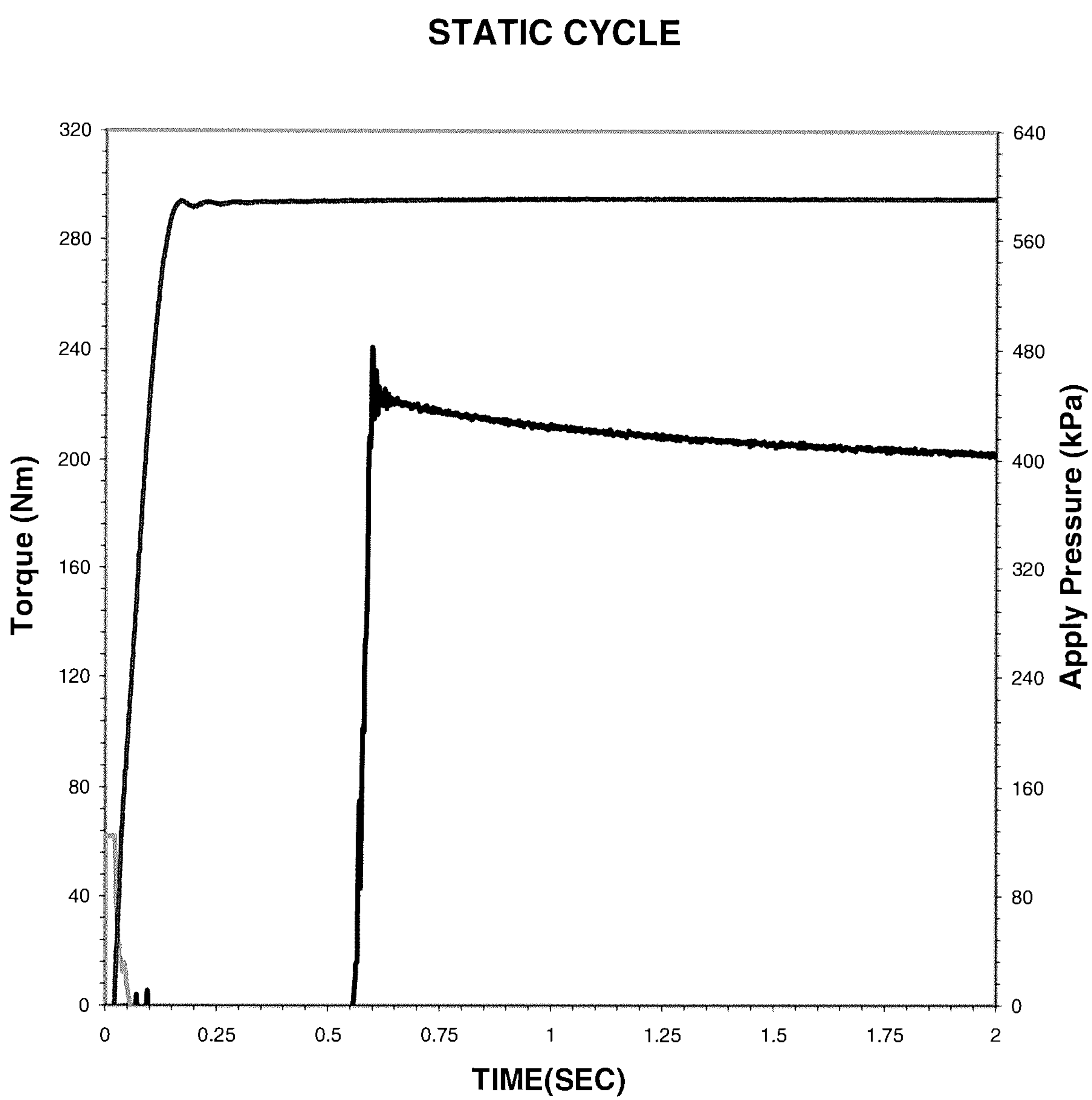
0.2 Sec Dyn:	226 N*m
Midpoint Dyn:	227 N*m
LwSpd Dynamic:	229 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.112

STATIC TRACES

ALLISON C-4 PAPER DATA



Date of Test: 10/13/2011

Time of Test: 14:55:24

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 10

STATIC CYCLE

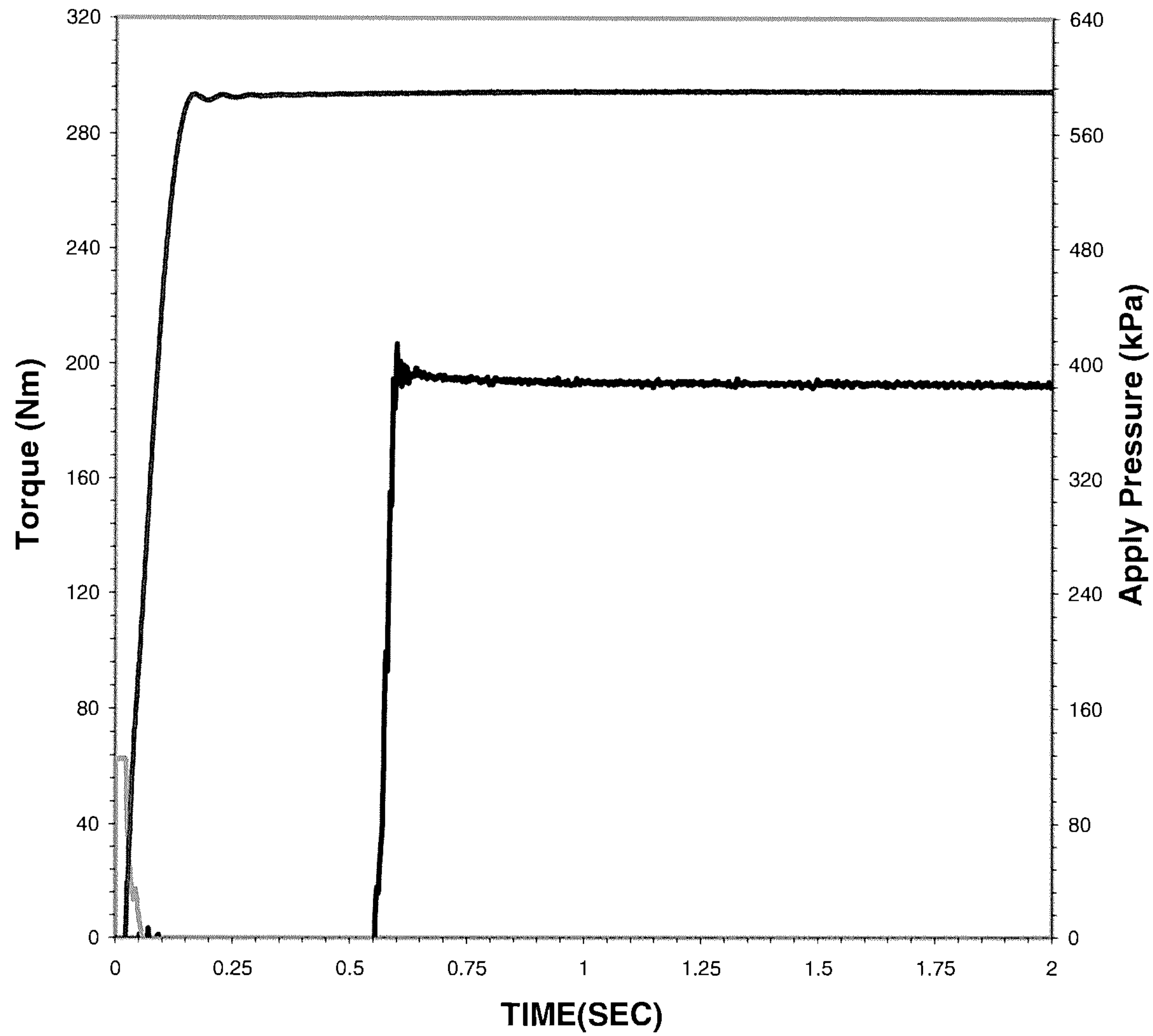
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 244 Nm
.25 Second: 219 Nm

Coefficient of Friction
Static Peak: 0.119
.25 Second: 0.107

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/13/2011

Time of Test: 15:18:11

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 100

STATIC CYCLE

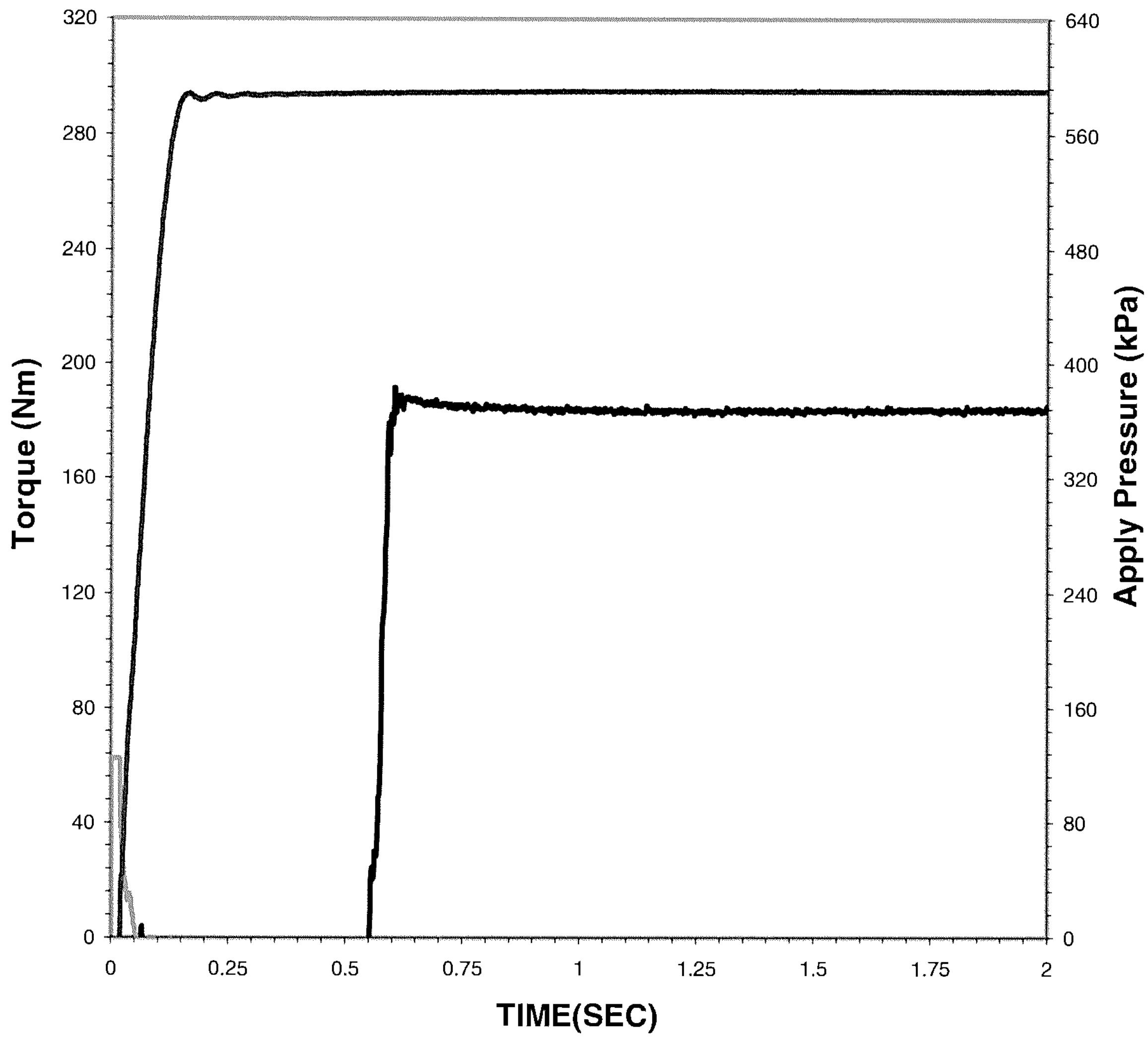
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 210 Nm
.25 Second: 196 Nm

Coefficient of Friction
Static Peak: 0.102
.25 Second: 0.095

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/13/2011

Time of Test: 16:58:27

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 500

STATIC CYCLE

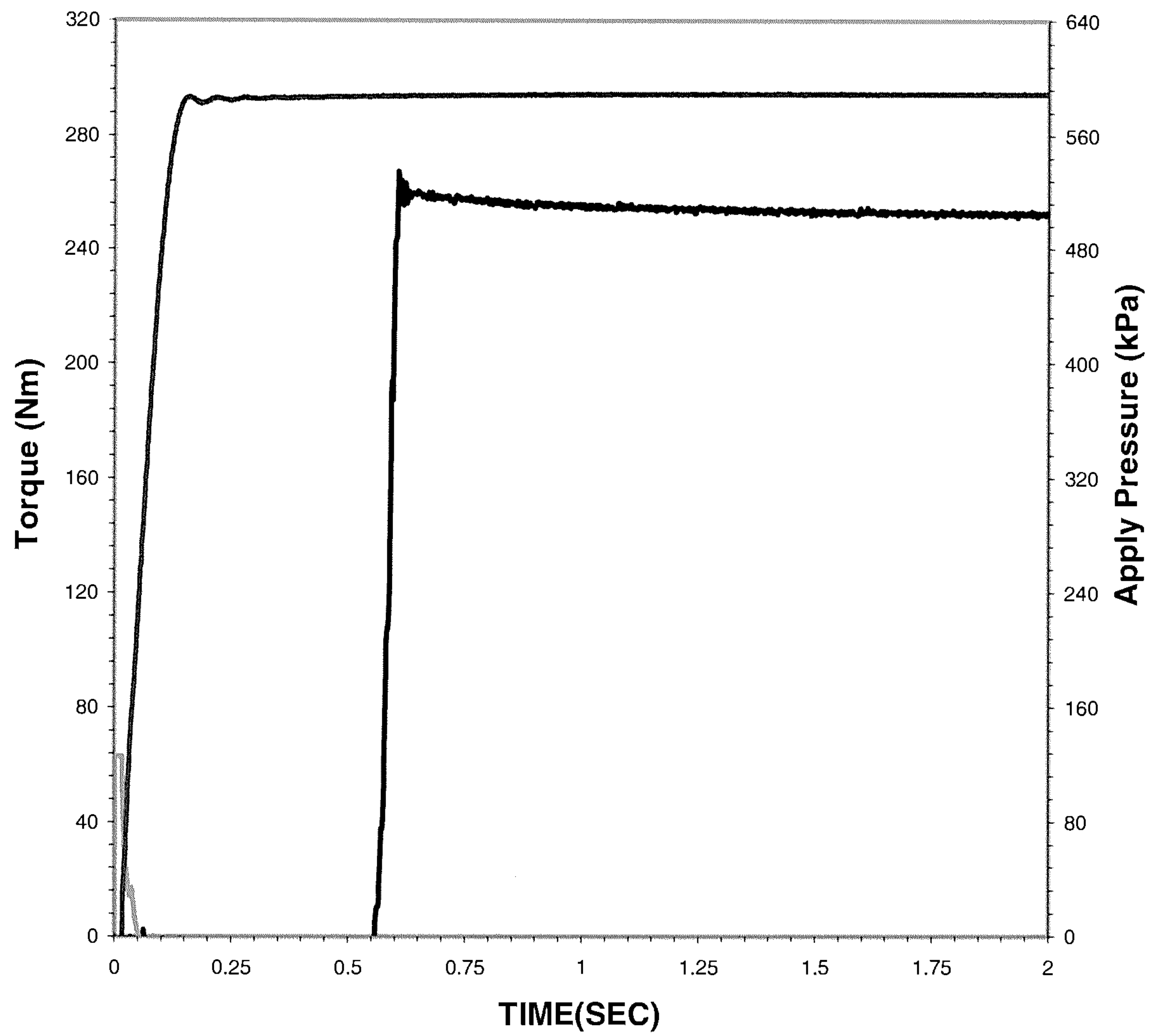
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 195 Nm
.25 Second: 189 Nm

Coefficient of Friction
Static Peak: 0.095
.25 Second: 0.092

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/13/2011

Time of Test: 19:03:43

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 1000

STATIC CYCLE

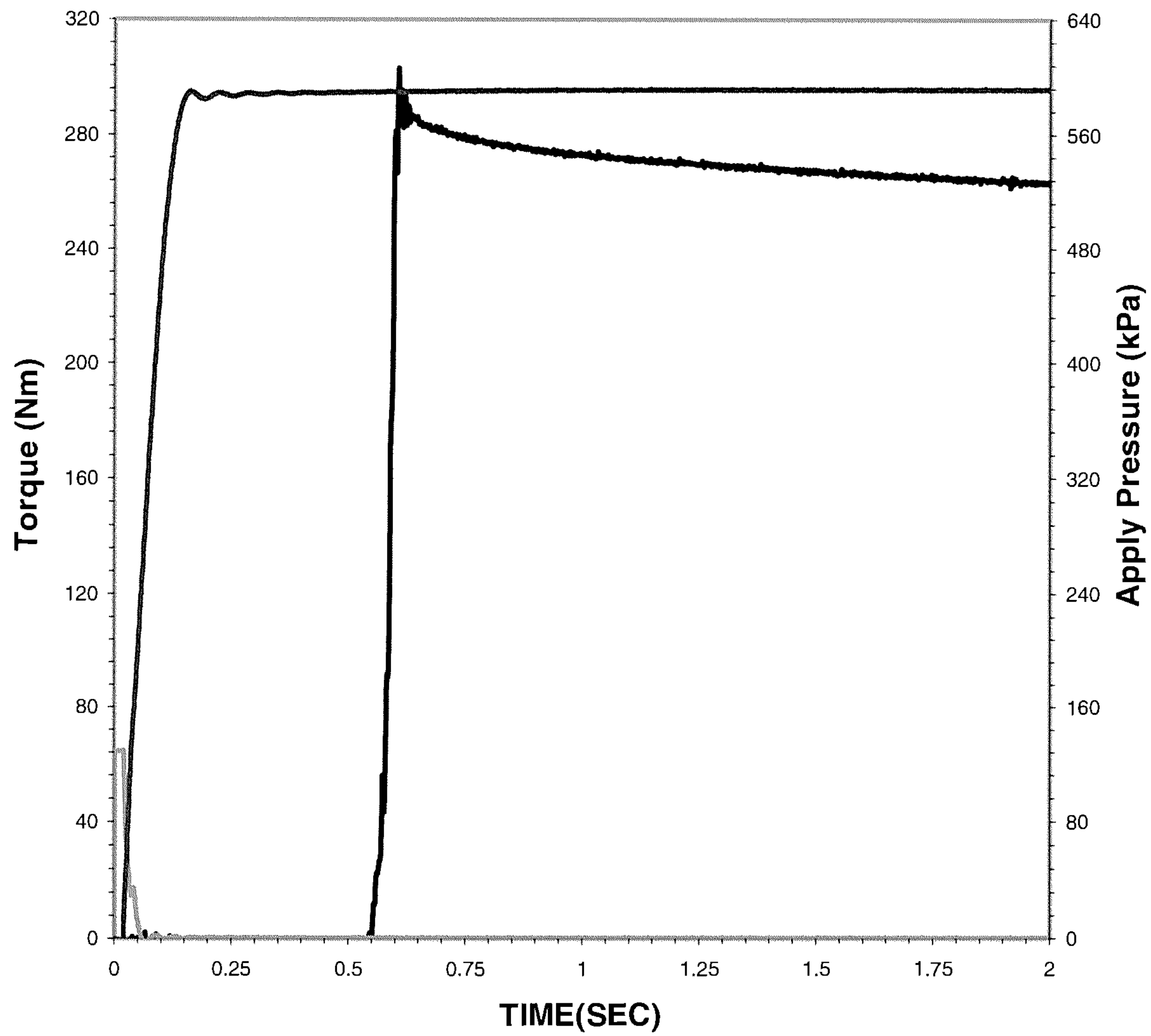
Apply Pressure:
At .25 Second: 587 kPa

Torque
Static Peak: 271 Nm
.25 Second: 260 Nm

Coefficient of Friction
Static Peak: 0.132
.25 Second: 0.127

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 1:18:59

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 2500

STATIC CYCLE

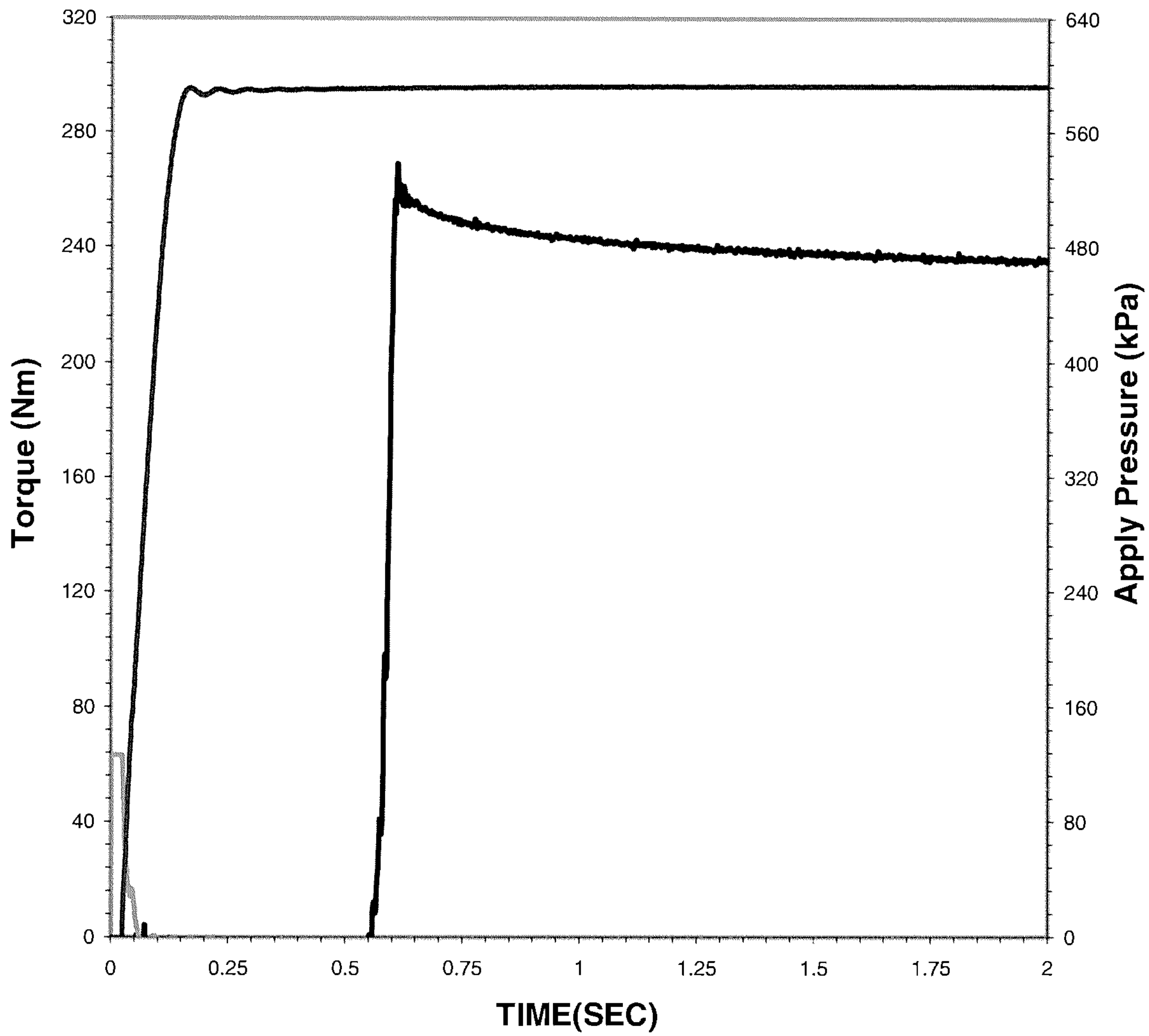
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 306 Nm
.25 Second: 280 Nm

Coefficient of Friction
Static Peak: 0.149
.25 Second: 0.136

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 11:43:05

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 5000

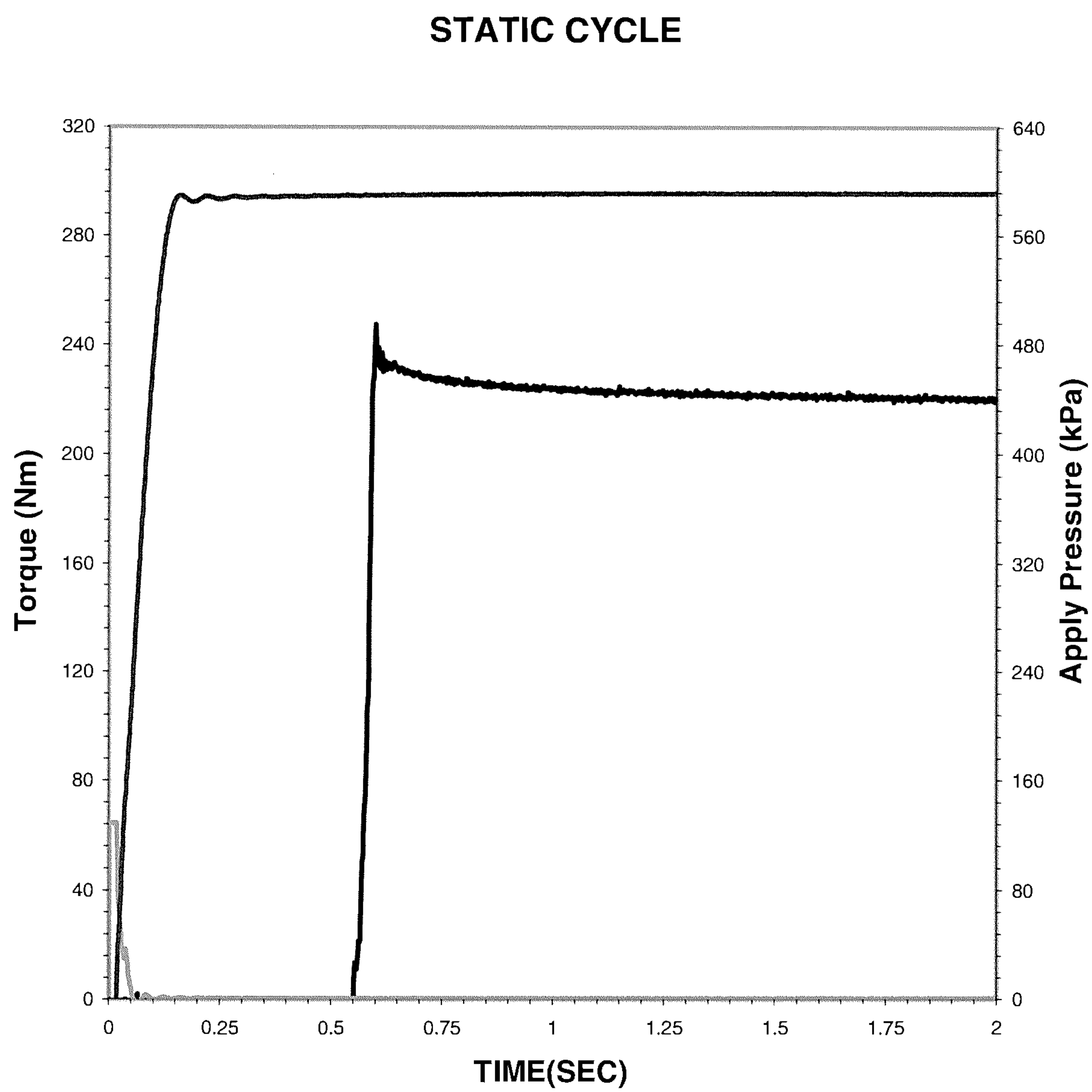
STATIC CYCLE

Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 272 Nm
.25 Second: 249 Nm

Coefficient of Friction
Static Peak: 0.133
.25 Second: 0.121

ALLISON C-4 PAPER DATA



Date of Test: 10/14/2011

Time of Test: 22:08:21

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 7500

STATIC CYCLE

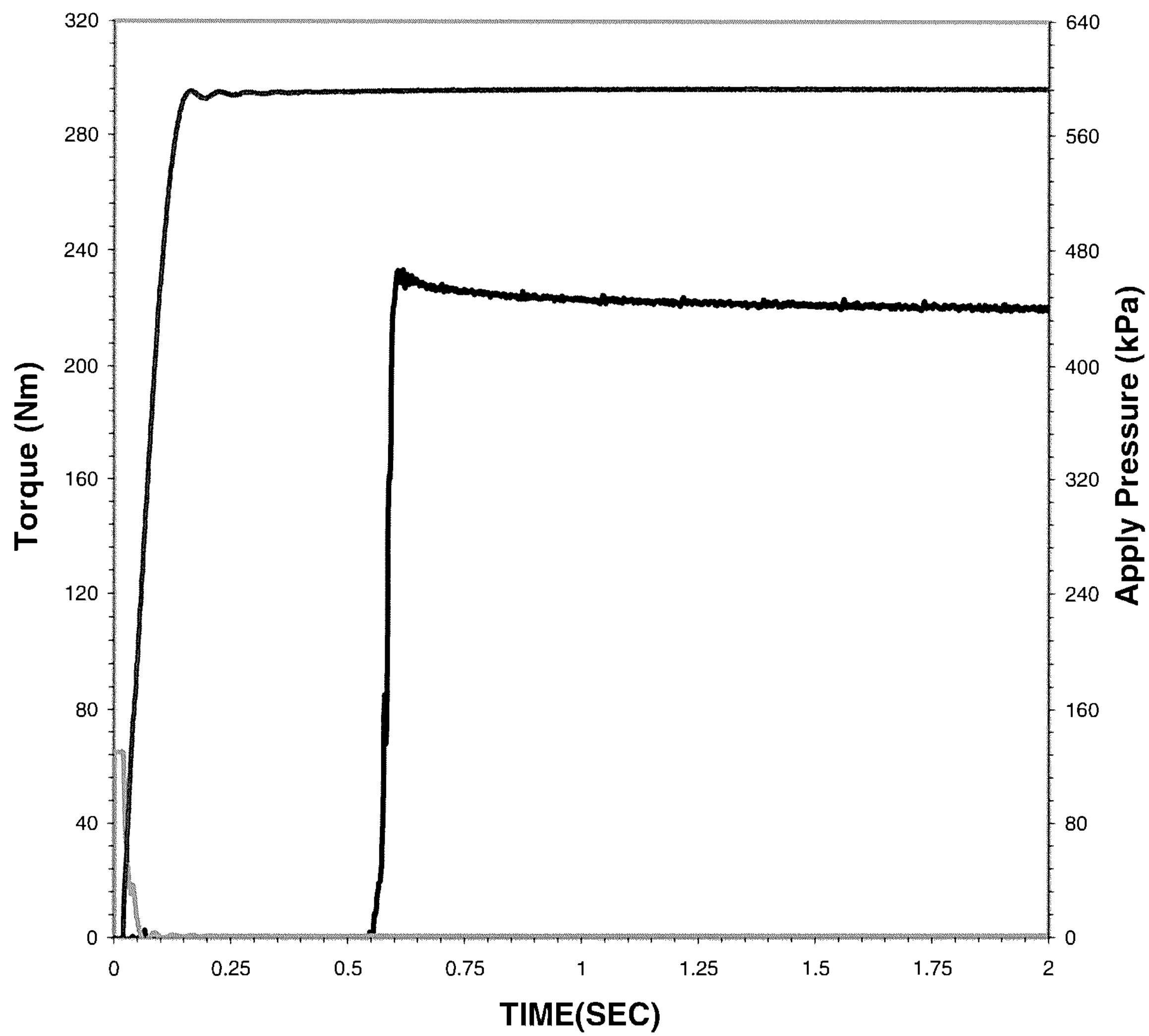
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 251 Nm
.25 Second: 229 Nm

Coefficient of Friction
Static Peak: 0.122
.25 Second: 0.112

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 8:33:37

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 10000

STATIC CYCLE

Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 236 Nm
.25 Second: 227 Nm

Coefficient of Friction
Static Peak: 0.115
.25 Second: 0.111

APPENDIX – D2 (PART 1)
TYPE C-4 GRAPHITE CLUTCH FRICTION TEST
LO271510

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

Allison Heavy-Duty Transmission Fluid
TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

ARMY LAB

Oil Code:
LO271510

Test Number:
C4-4-1342

October 15, 2011

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluid Evaluations

VIII. Graphite Clutch Friction Test

Test Laboratory: SWRI
Test Number: C4-4-1342
Friction Plate Batch: LOT 44
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-271510
Sponsor Fluid Code: LO271510
Completion Date: 10/15/11

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0840	0.0762

	Before	After
Pack Clearance	0.4826	0.6096

Reference Tests

Test Number	Test Date	Test Fluid
C4-0-1304	12/09/10	PASS REF-L-06-04
C4-0-1315	03/30/11	MIL-PRF-2104H
C4-0-1338	10/05/11	MIL-PRF-2104H

	New	EOT
Viscosity at 40°C, cSt	45.26	39.12
Viscosity at 100°C, cSt	8.45	7.55
Iron Content, ppm	1	83

D5185	New Fluid (ppm)
Ba	<1
B	18
Ca	904
Mg	1261
P	1063
Si	6
Na	<5
Zn	1261

Name: Matthew Jackson

Signature:

Title: Manager

Date: 10/25/11

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO271510**	Test Number:	**C4-4-1342**
Lab Fluid Code:	**LO-271510**	Fric. Plate Batch:	**LOT 44**
Completion Date:	**10/15/2011**	Steel Plate Batch:	**10/9/2008**

PHASE A

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
500	1.21	50	73	39	34	88	72
1000	1.26	48	71	35	36	91	71

PHASE B

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (0.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
1500	0.76	104	149	92	57	175	157
2000	0.80	99	145	83	62	162	154
2500	0.82	96	143	78	65	167	154
3500	0.84	95	140	77	63	164	152
4000	0.83	96	141	75	66	164	150
4500	0.85	94	137	75	62	164	150
5000	0.83	97	141	75	66	162	149
5500	0.81	100	137	82	55	158	149

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.76	0.81	6.58	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.086	0.077	-10.465	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.097	0.094	-3.093	P
Static Friction Coeff.	N/A	N/A	0.140	0.128	-8.571	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.164	0.148	-9.756	
0.25 Second Low Speed Coeff.	N/A	N/A	0.147	0.140	-4.762	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-GRAPHITE FRICTION TEST

Candidate Fluid: LO271510 | **Test Number : C4-4-1342** | **Completion Date : 10/15/2011**

Lab Fluid Code : LO-271510 | **Steel Plate Batch: 10/09/2008** | **Fric Plate Batch : LOT 44**

(all units in mm)

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.2050	2.1220	2.2200	2.1430	0.0830		0.0770
	120	2.2180	2.1340	2.2190	2.1460	0.0840		0.0730
	240	2.2100	2.1340	2.2090	2.1450	0.0760		0.0640
	Average					0.0810	0.0762	0.0713
STEEL SEPARATORS								
1	Top	1.7630	1.7630	1.7630	1.7630	0.0000		0.0000
	120	1.7600	1.7600	1.7600	1.7600	0.0000		0.0000
	240	1.7620	1.7620	1.7620	1.7620	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7590	1.7590	1.7590	1.7590	0.0000		0.0000
	120	1.7580	1.7580	1.7580	1.7580	0.0000		0.0000
	240	1.7590	1.7590	1.7590	1.7590	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T. STEEL PLATES HAVE NO UNUSUAL DISCOLORATION
(Anything Unusual)

Test Date: 10/15/2011

Operator's Name: JOE M

Reviewed By (Signature and Date)

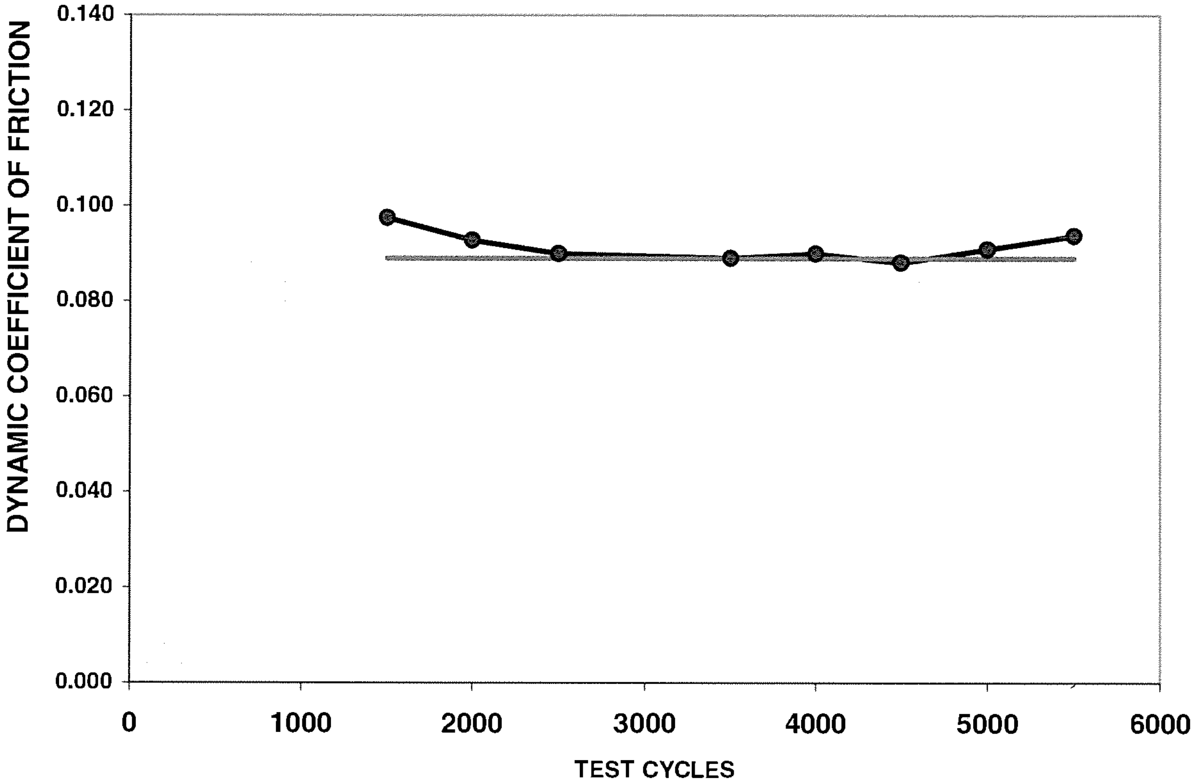
10/24/11

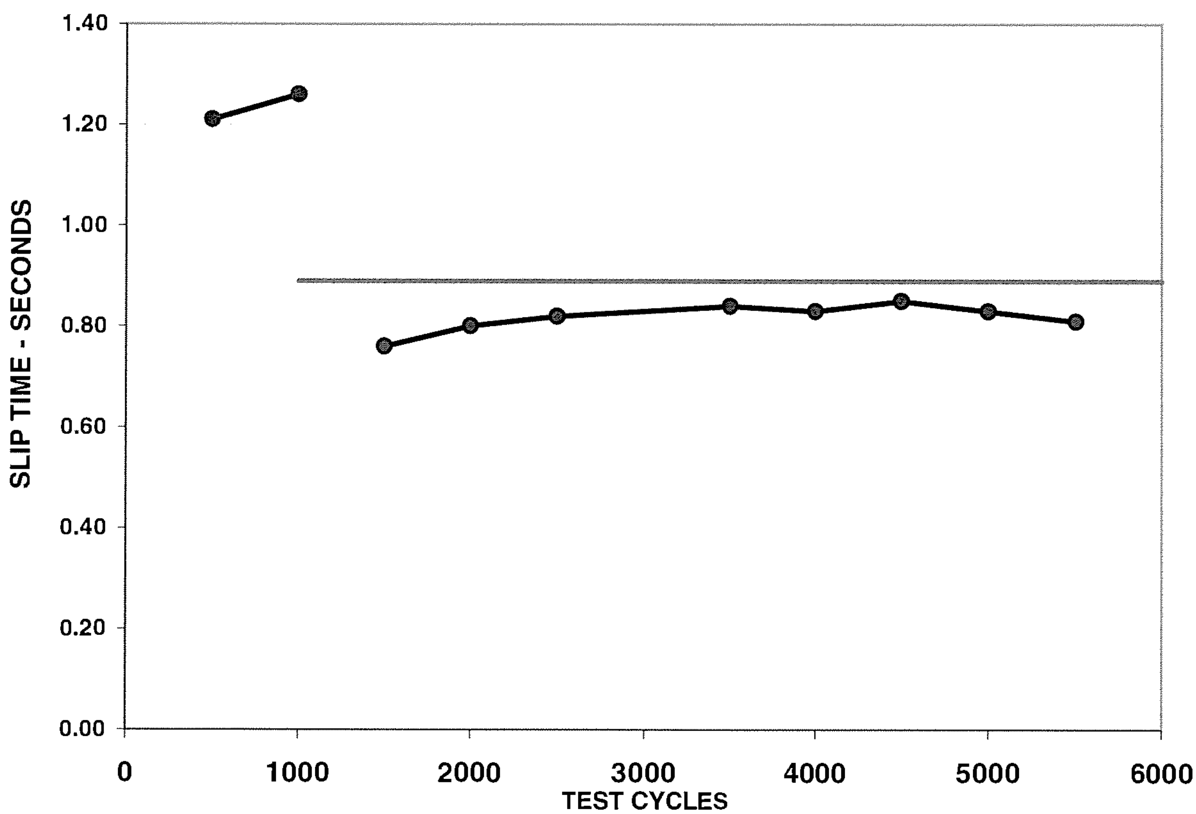
Pack ID#: 4668

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST

EOT Date: 10/15/2011
Test Number: C4-4-1342

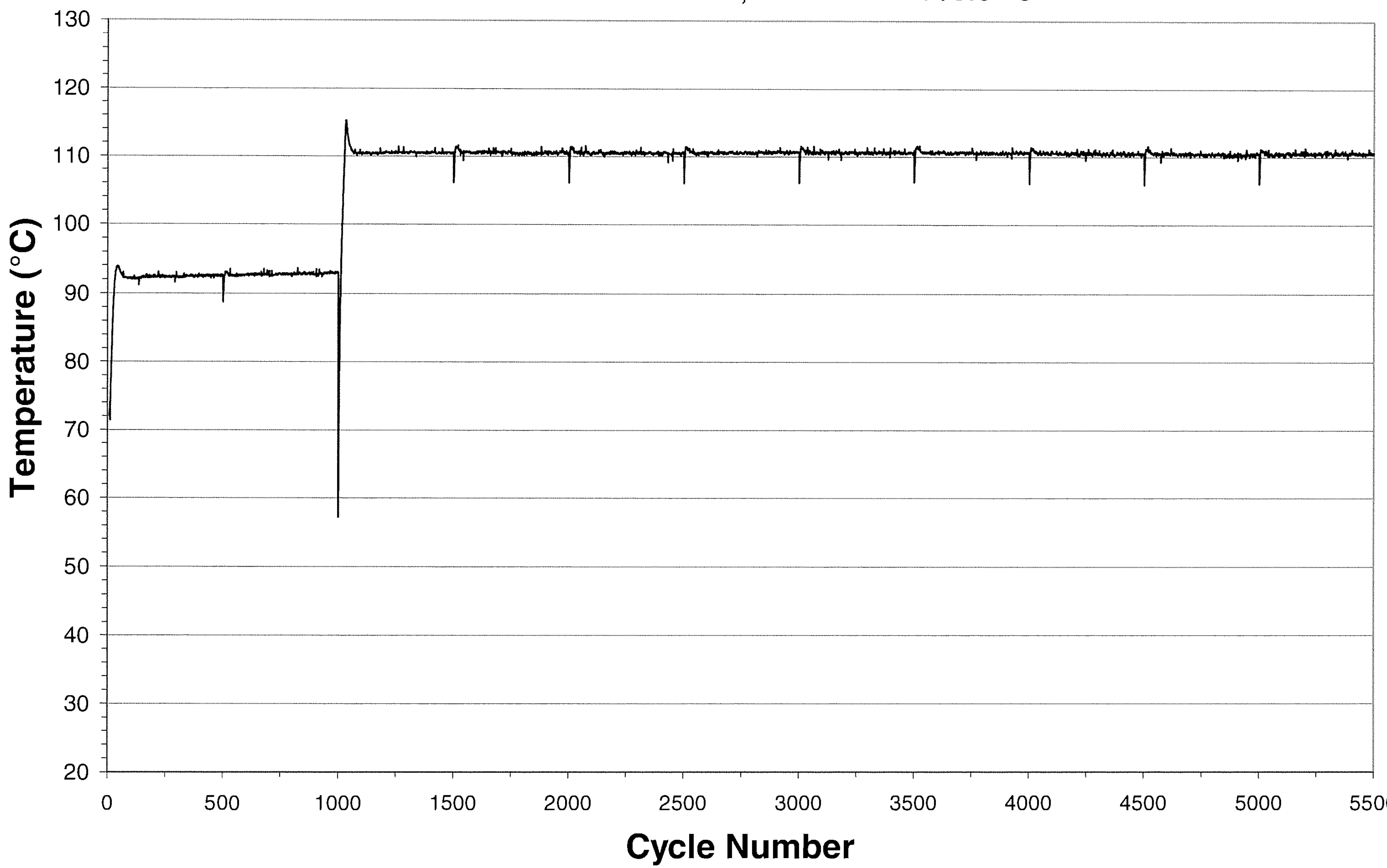
Fluid Code: LO271510
Plate Batch: LOT 44
Steel Batch: 10/9/2008





C4-4-1342 LO271510

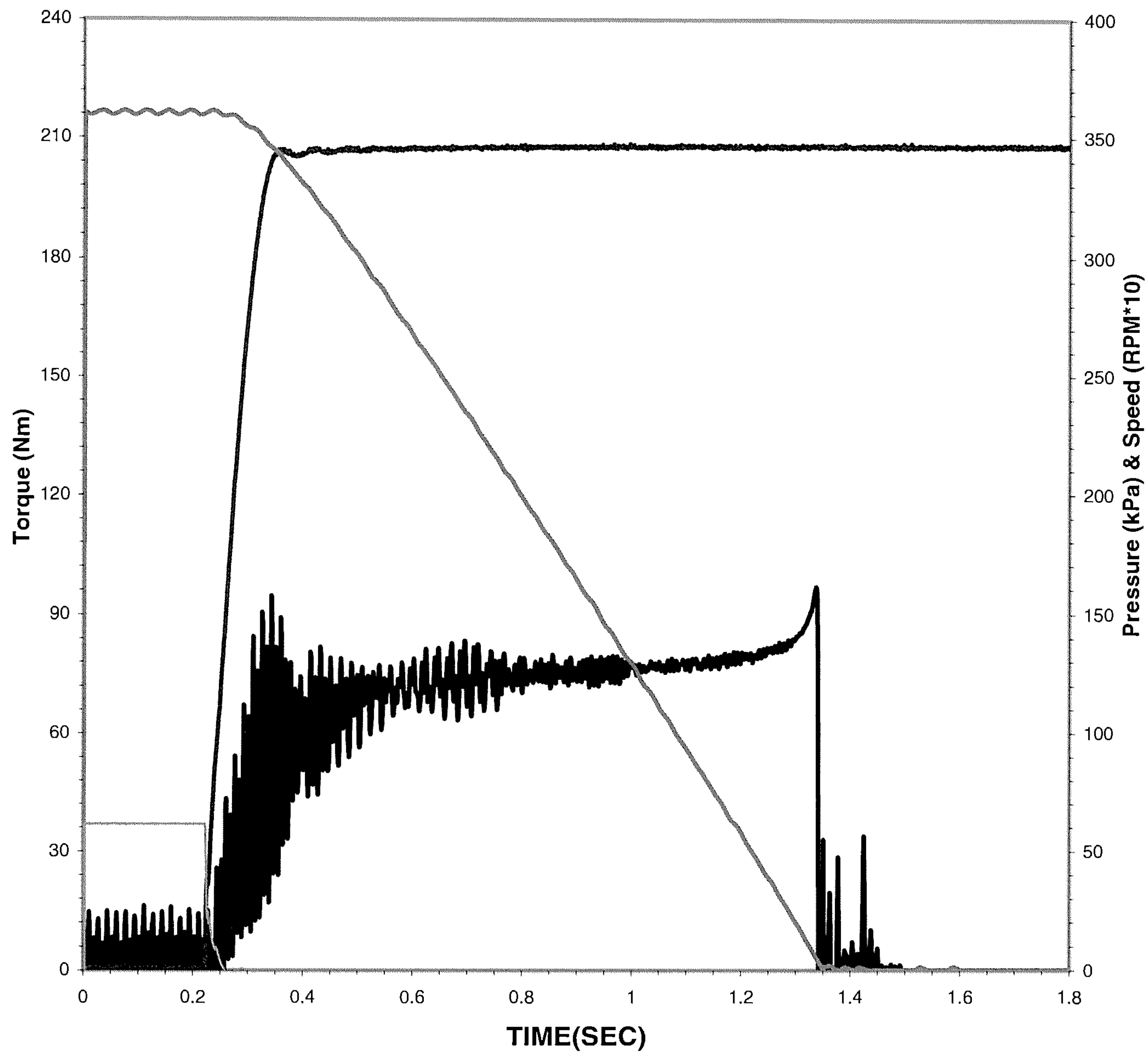
AVG: Phase A = 92.2 °C, Phase B = 110.5 °C



DYNAMIC TRACES

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/14/2011
Time of Test:	16:27:01
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	10
Temperature:	74.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	345 kPa (345 ± 7 KPa)
Apply Rate:	0.12 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.118 Sec

Torque

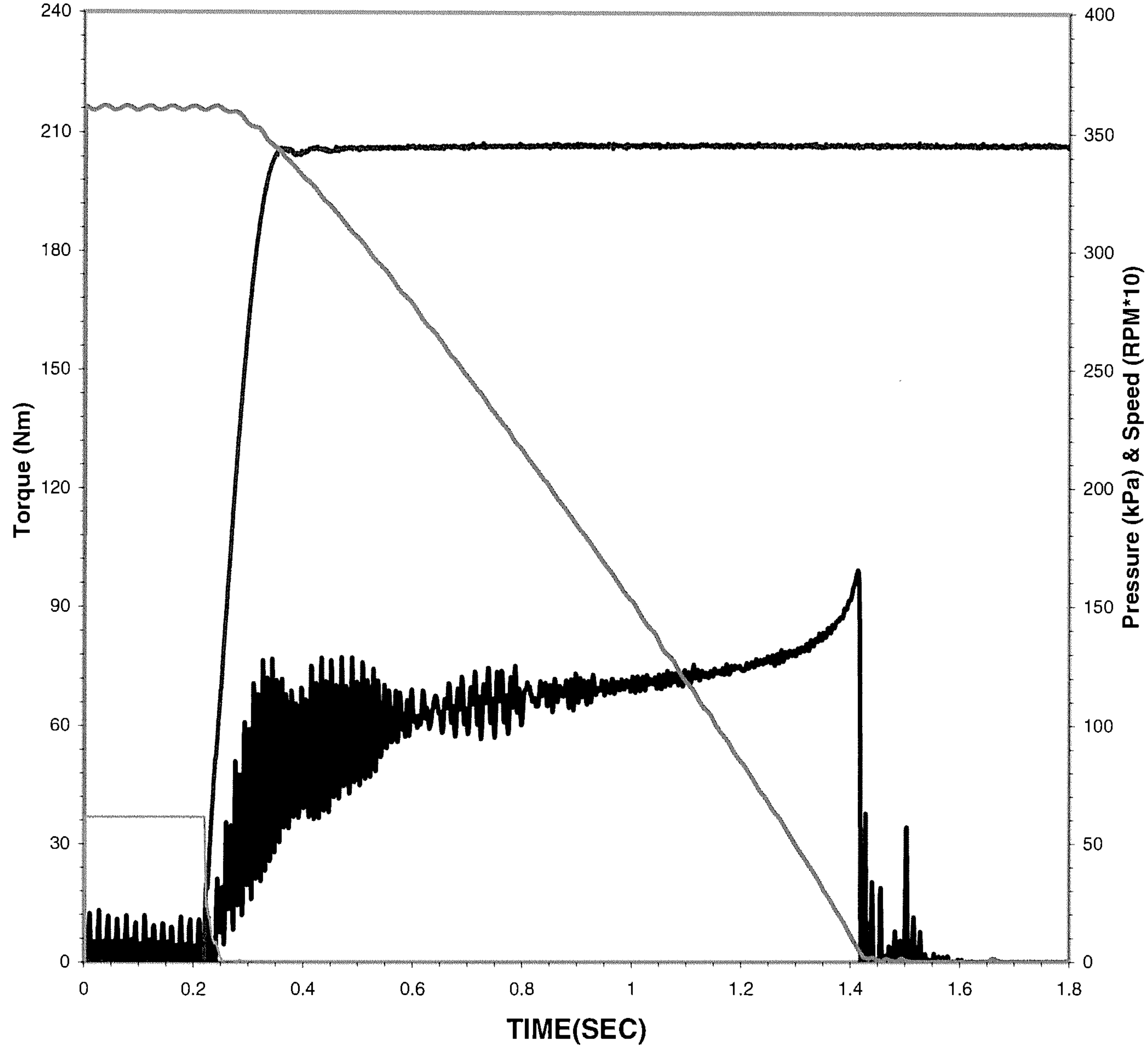
0.2 Sec Dyn:	62 N*m
Midpoint Dyn:	76 N*m
LwSpd Dynamic:	95 N*m

Coefficient of Friction

.2 Sec Dyn:	0.102
Midpoint Dyn:	0.125
LwSpd Dynamic:	0.157

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/14/2011
Time of Test:	18:29:27
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	499
Temperature:	92.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	345 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.197 Sec

Torque

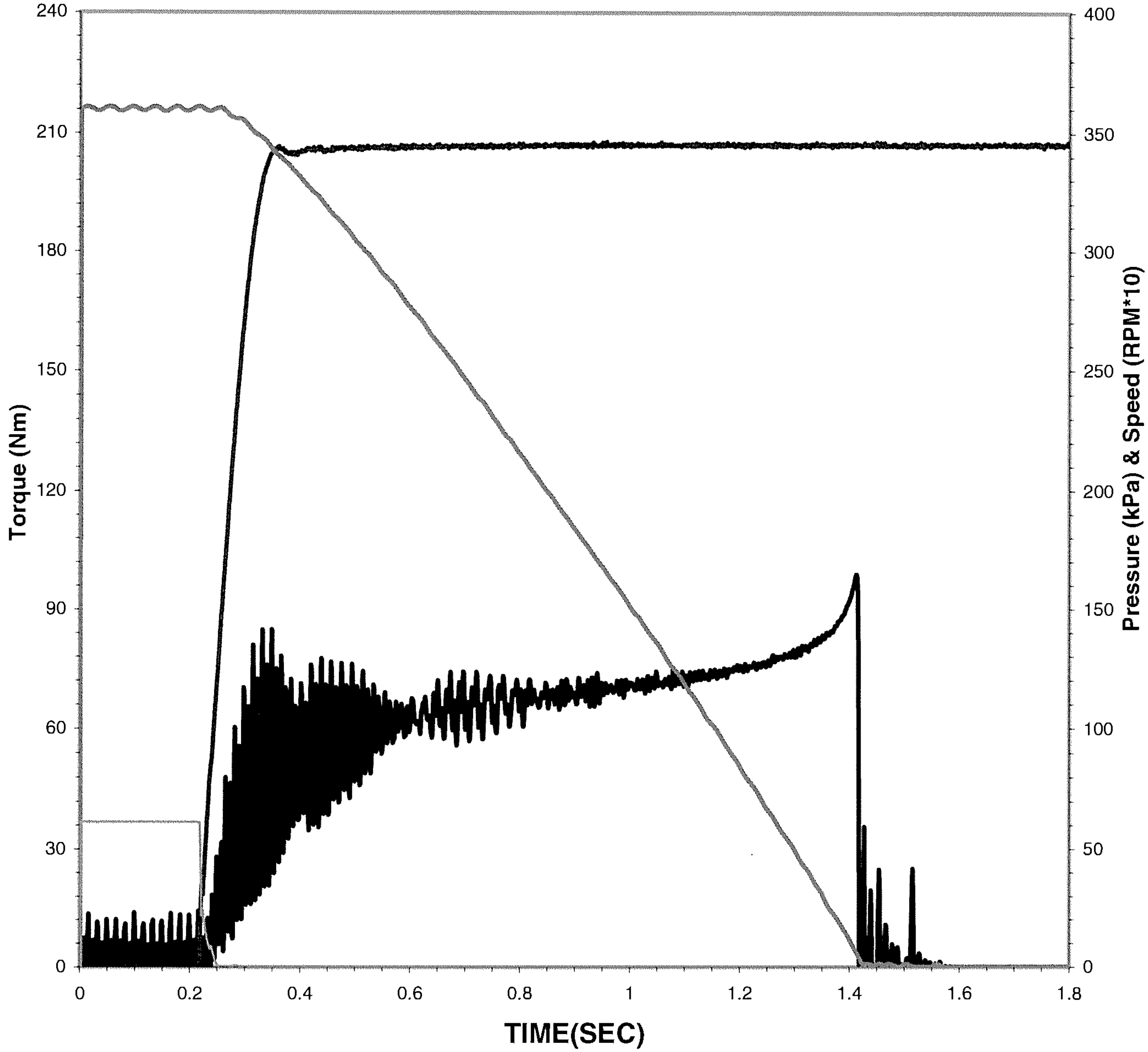
0.2 Sec Dyn:	54 N*m
Midpoint Dyn:	68 N*m
LwSpd Dynamic:	97 N*m

Coefficient of Friction

.2 Sec Dyn:	0.090
Midpoint Dyn:	0.113
LwSpd Dynamic:	0.160

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/14/2011
Time of Test:	18:29:43
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	500
Temperature:	92.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.198 Sec

Torque

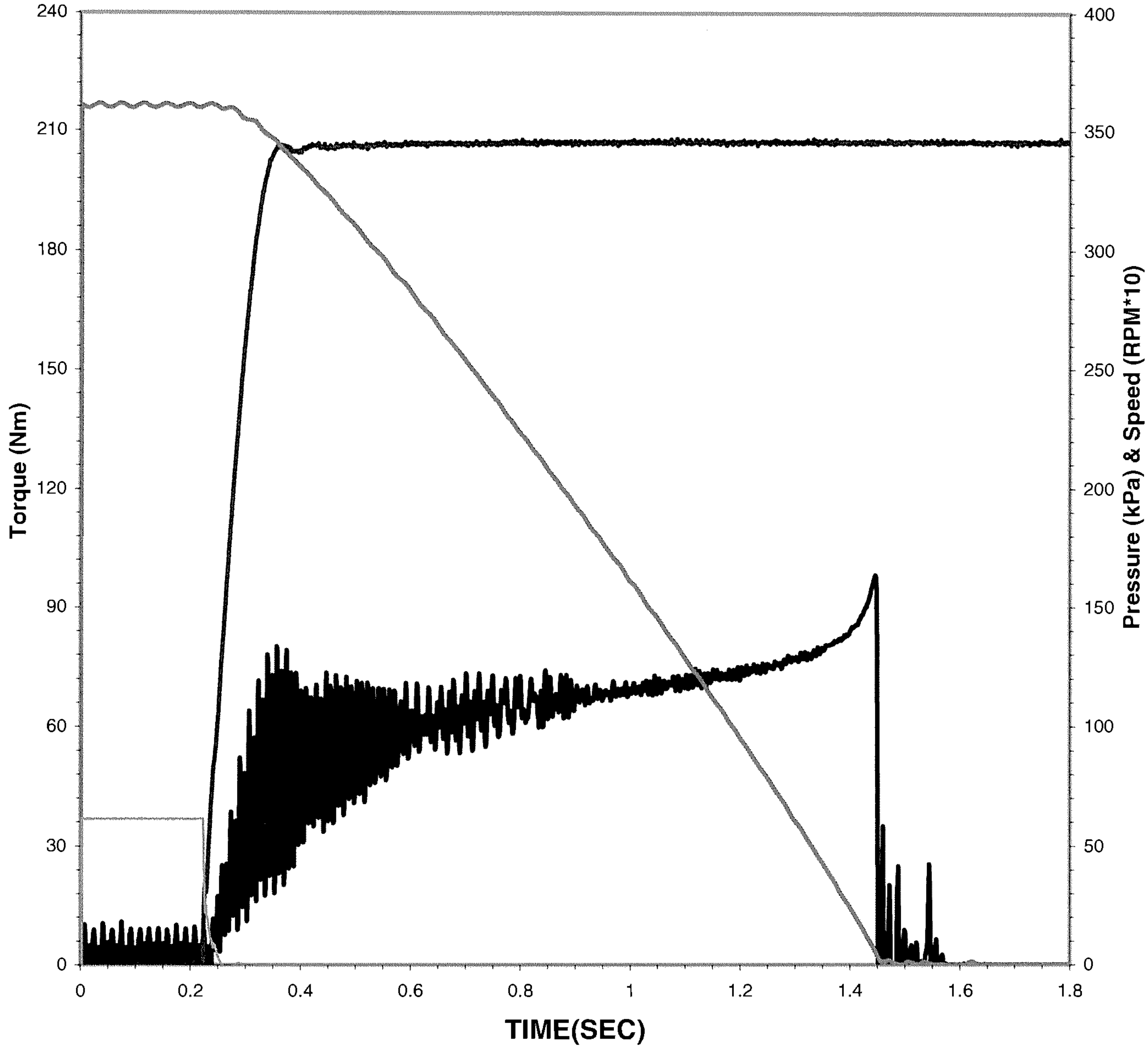
0.2 Sec Dyn:	54 N*m
Midpoint Dyn:	68 N*m
LwSpd Dynamic:	99 N*m

Coefficient of Friction

.2 Sec Dyn:	0.089
Midpoint Dyn:	0.113
LwSpd Dynamic:	0.164

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/14/2011
Time of Test:	18:30:09
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	501
Temperature:	88.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.226 Sec

Torque

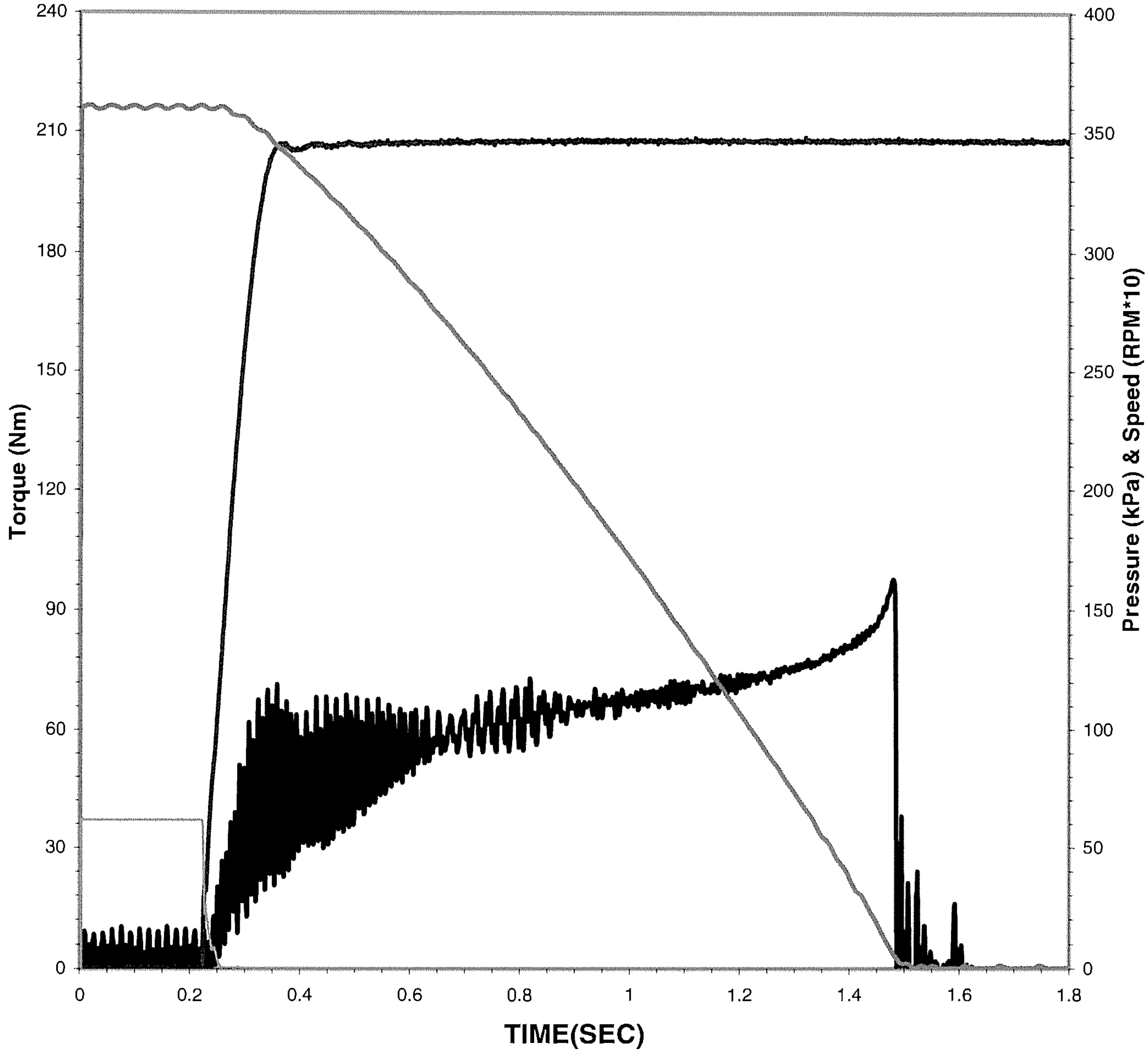
0.2 Sec Dyn:	52 N*m
Midpoint Dyn:	67 N*m
LwSpd Dynamic:	98 N*m

Coefficient of Friction

.2 Sec Dyn:	0.087
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.163

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/14/2011
Time of Test:	20:34:24
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	998
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.26 Sec

Torque

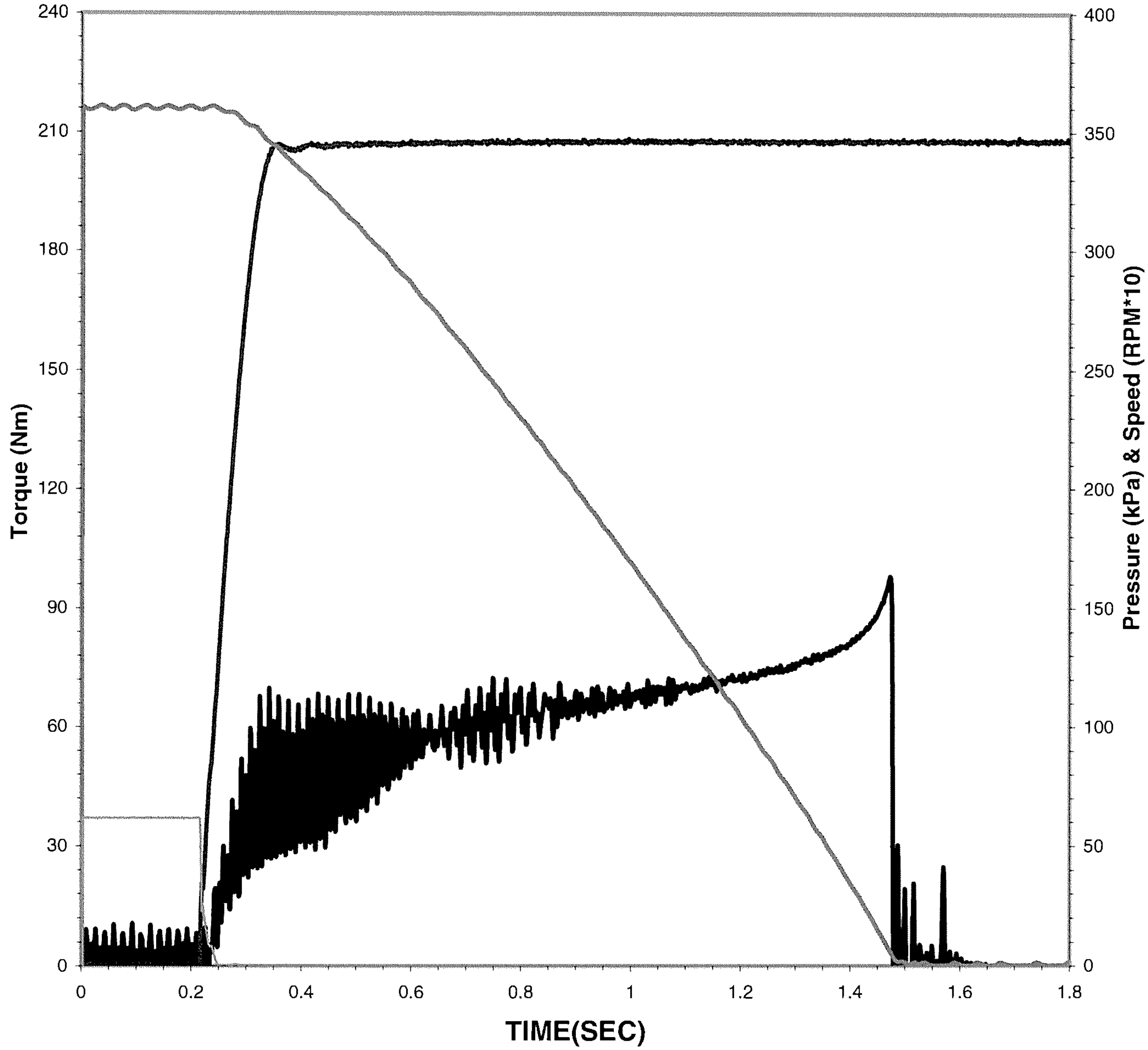
0.2 Sec Dyn:	47 N*m
Midpoint Dyn:	65 N*m
LwSpd Dynamic:	95 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.158

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/14/2011
Time of Test:	20:34:39
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	999
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.261 Sec

Torque

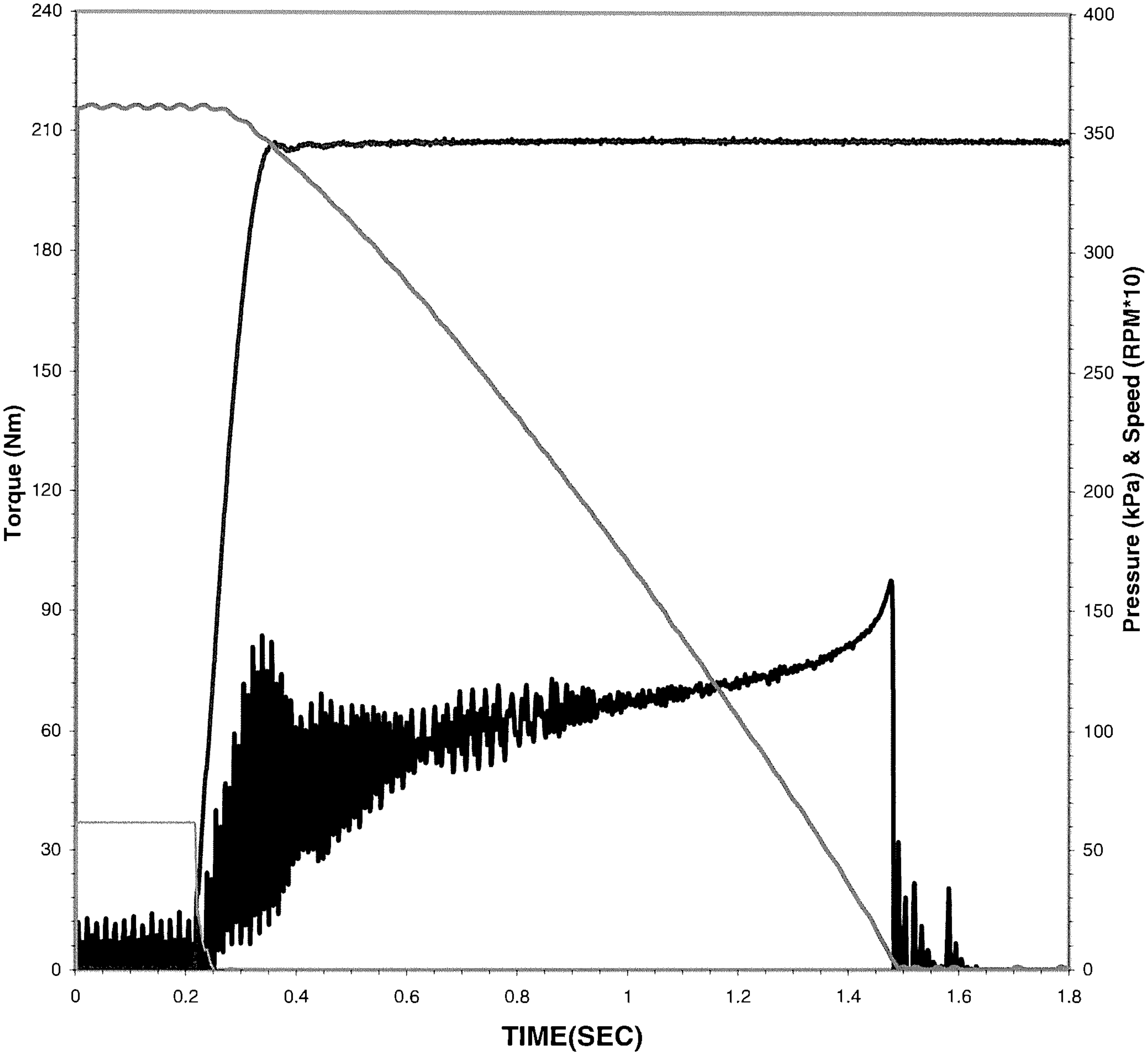
0.2 Sec Dyn:	47 N*m
Midpoint Dyn:	65 N*m
LwSpd Dynamic:	97 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.161

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	10/14/2011
Time of Test:	20:34:54
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	1000
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.264 Sec

Torque

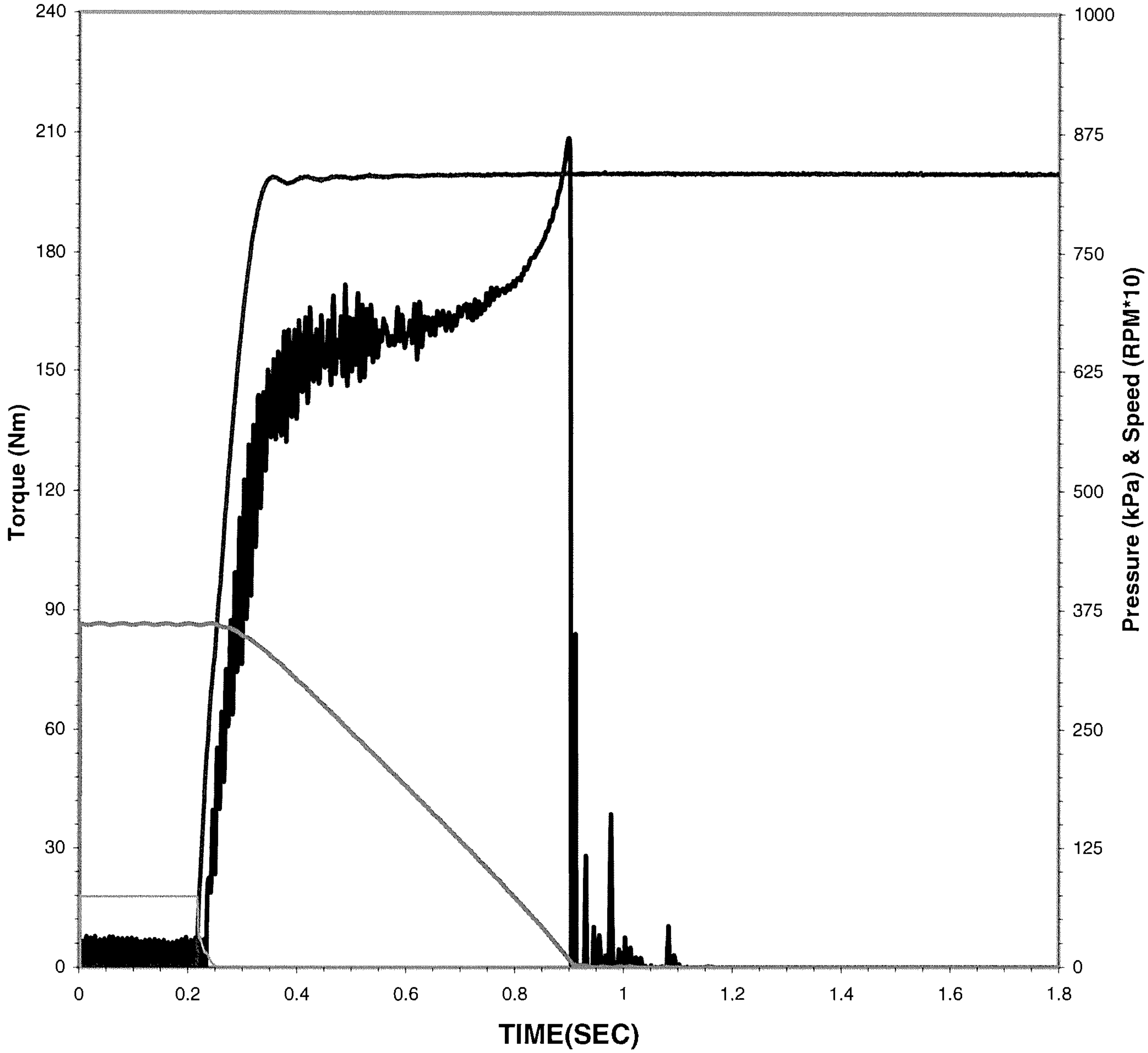
0.2 Sec Dyn:	47 N*m
Midpoint Dyn:	65 N*m
LwSpd Dynamic:	96 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.160

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	21:26:54
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	1010
Temperature:	90.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.688 Sec

Torque

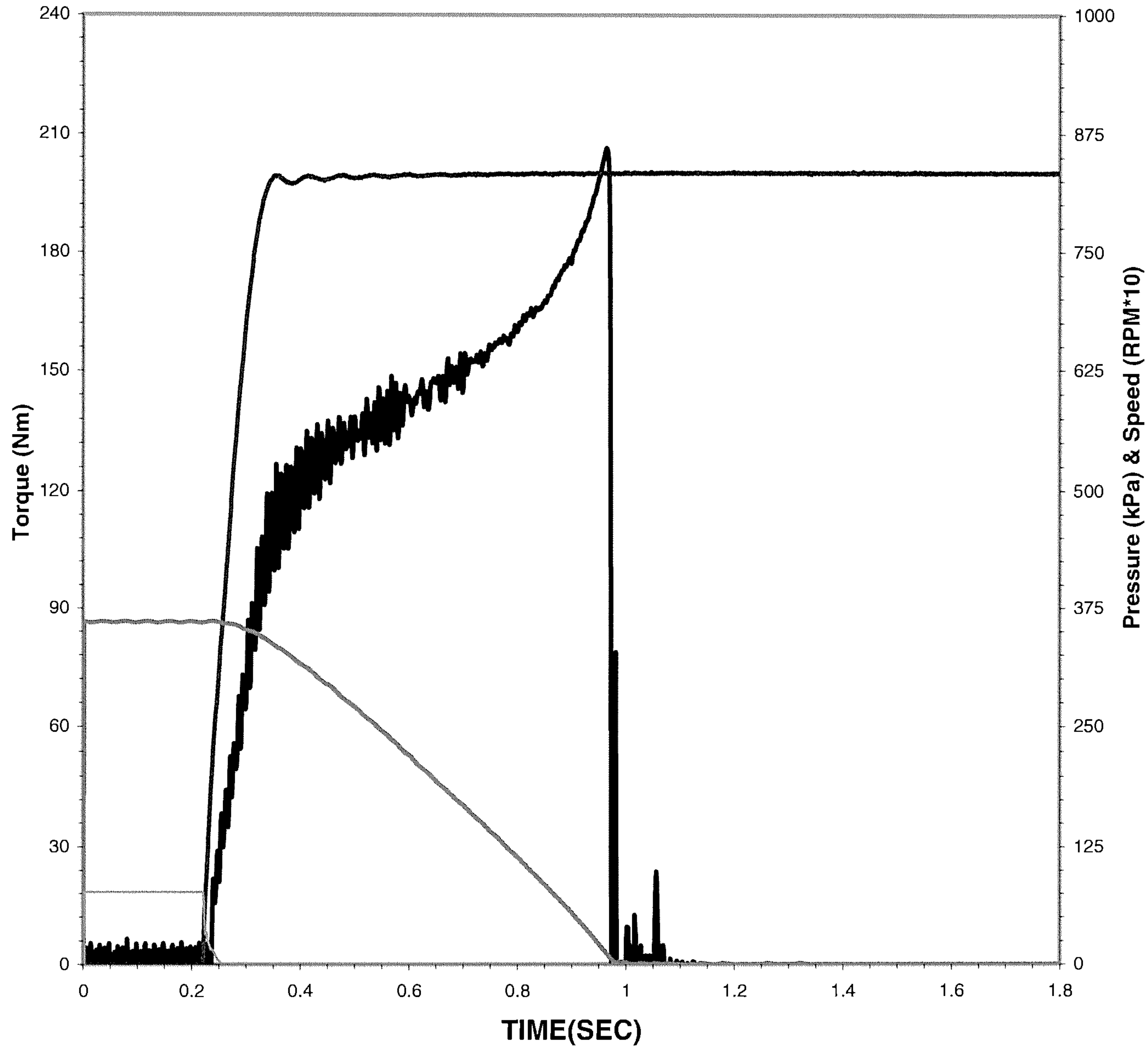
0.2 Sec Dyn:	155 N*m
Midpoint Dyn:	159 N*m
LwSpd Dynamic:	206 N*m

Coefficient of Friction

.2 Sec Dyn:	0.107
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.142

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	23:29:09
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	1499
Temperature:	110.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.752 Sec

Torque

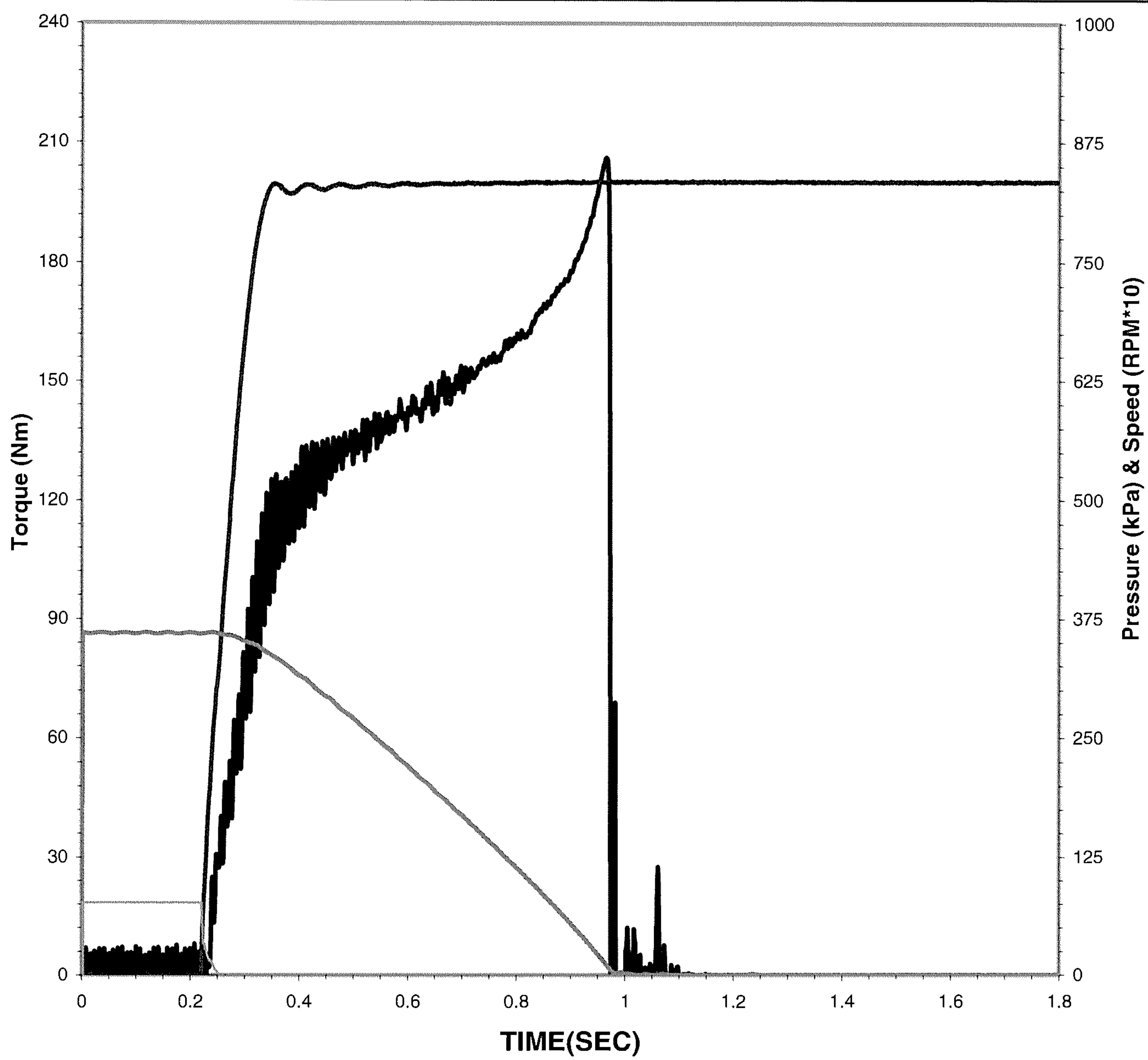
0.2 Sec Dyn:	125 N*m
Midpoint Dyn:	142 N*m
LwSpd Dynamic:	198 N*m

Coefficient of Friction

.2 Sec Dyn:	0.087
Midpoint Dyn:	0.098
LwSpd Dynamic:	0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	23:29:24
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	1500
Temperature:	110.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.754 Sec

Torque

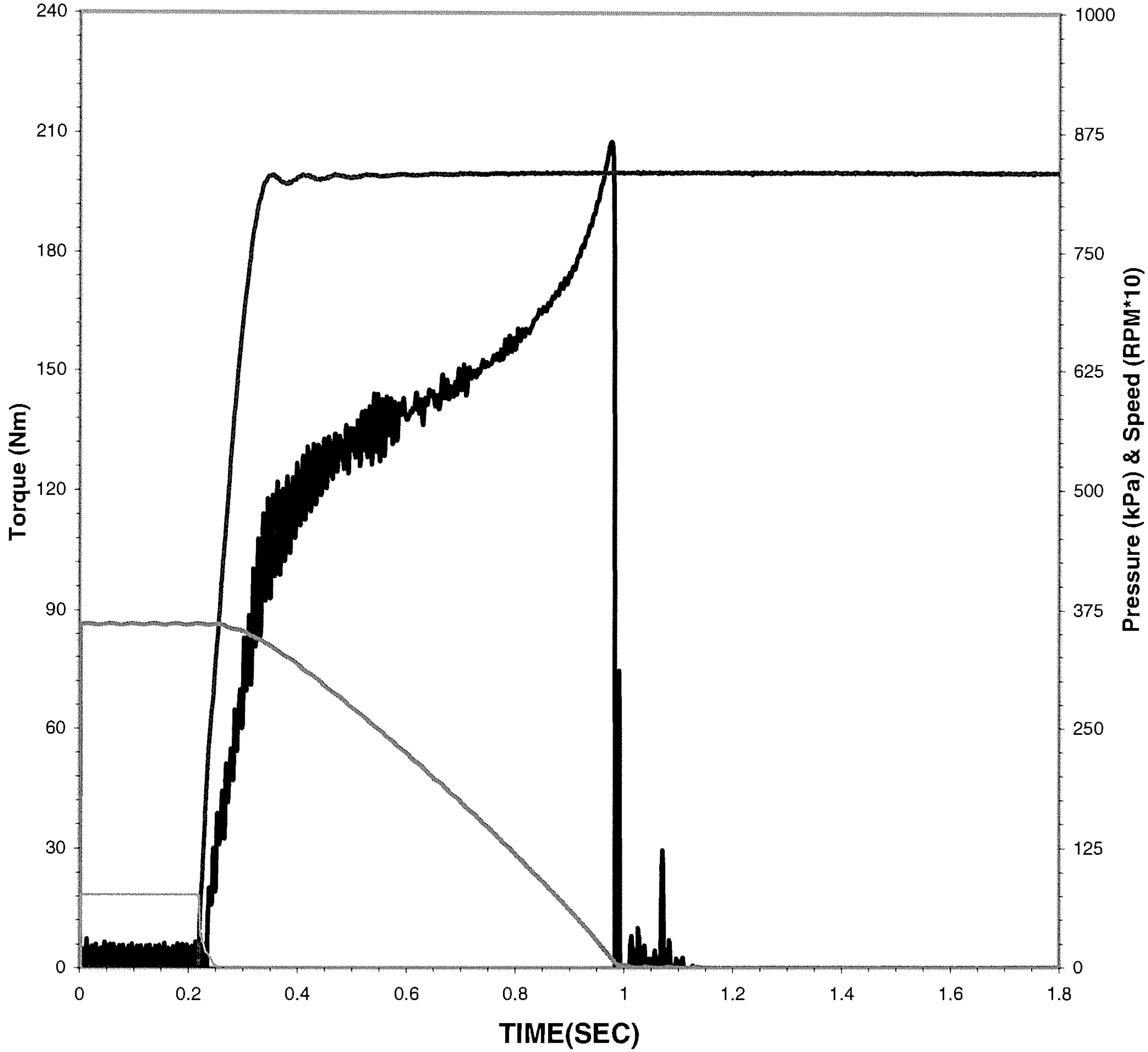
0.2 Sec Dyn:	126 N*m
Midpoint Dyn:	142 N*m
LwSpd Dynamic:	202 N*m

Coefficient of Friction

.2 Sec Dyn:	0.087
Midpoint Dyn:	0.098
LwSpd Dynamic:	0.139

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/14/2011
Time of Test:	23:29:51
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	1501
Temperature:	106.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.765 Sec

Torque

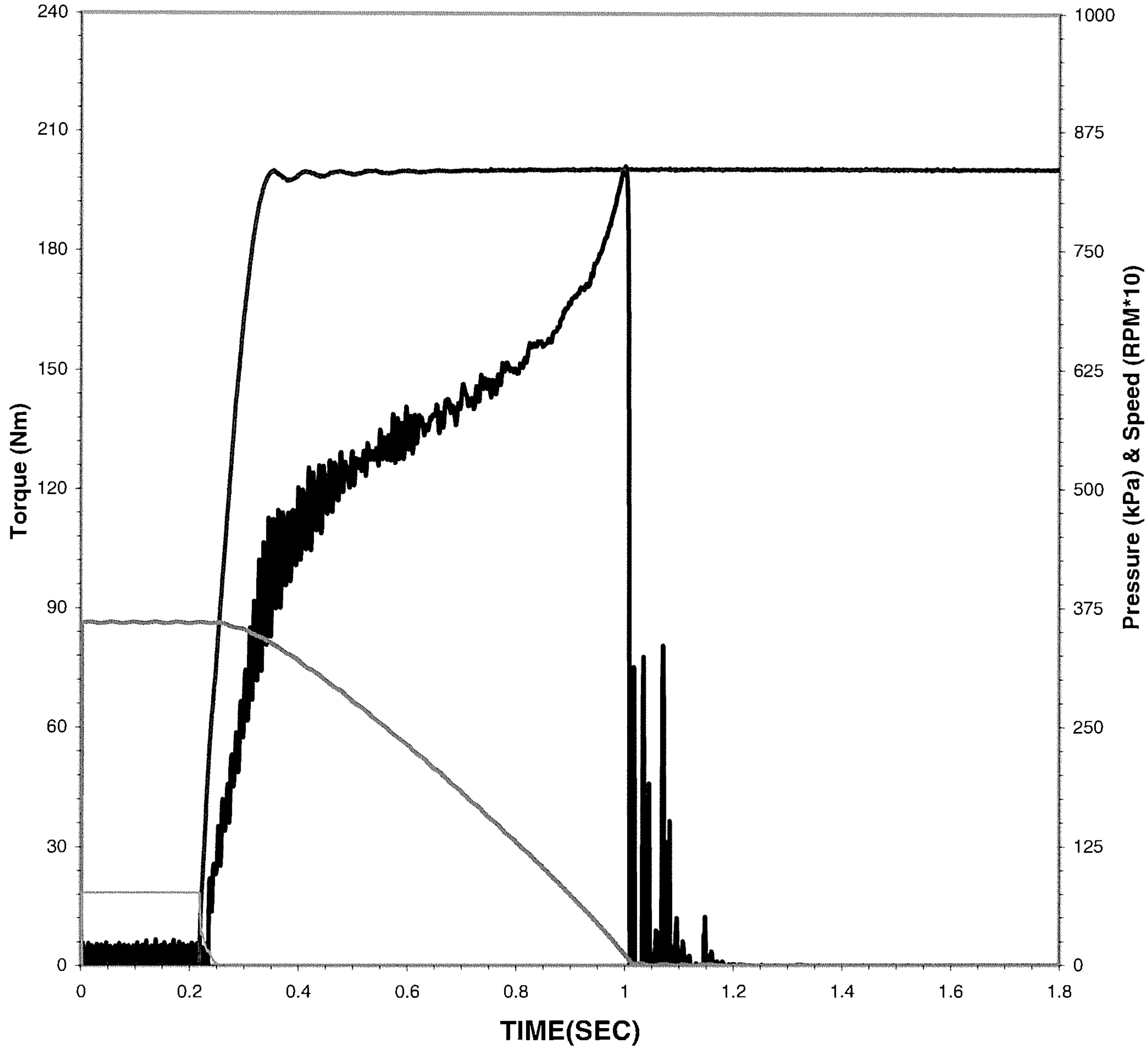
0.2 Sec Dyn:	122 N*m
Midpoint Dyn:	140 N*m
LwSpd Dynamic:	205 N*m

Coefficient of Friction

.2 Sec Dyn:	0.084
Midpoint Dyn:	0.097
LwSpd Dynamic:	0.141

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	1:34:21
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	1999
Temperature:	110.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.792 Sec

Torque

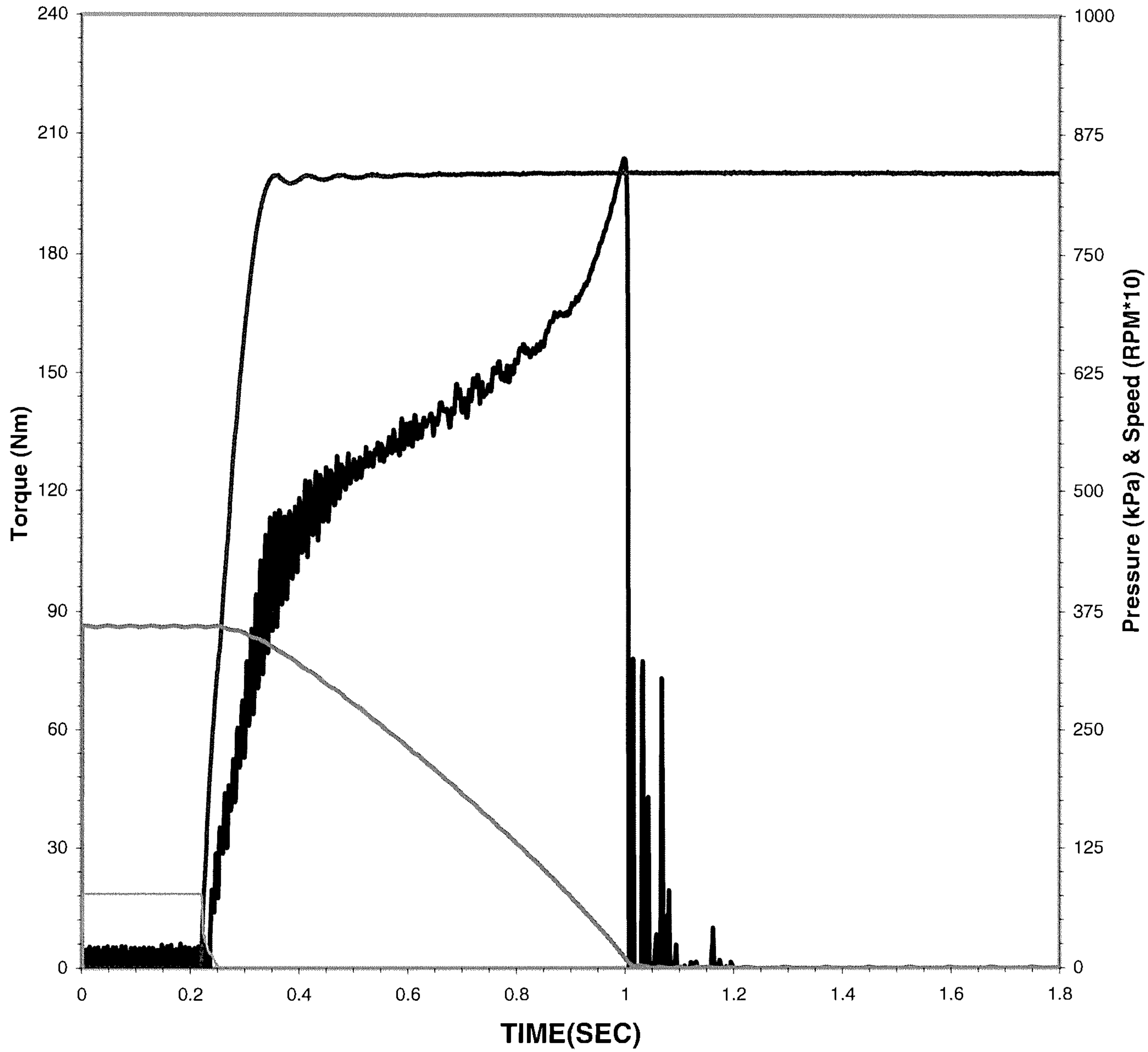
0.2 Sec Dyn:	114 N*m
Midpoint Dyn:	136 N*m
LwSpd Dynamic:	194 N*m

Coefficient of Friction

.2 Sec Dyn:	0.079
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.134

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	1:34:36
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	2000
Temperature:	110.5 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	832 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.786 Sec

Torque

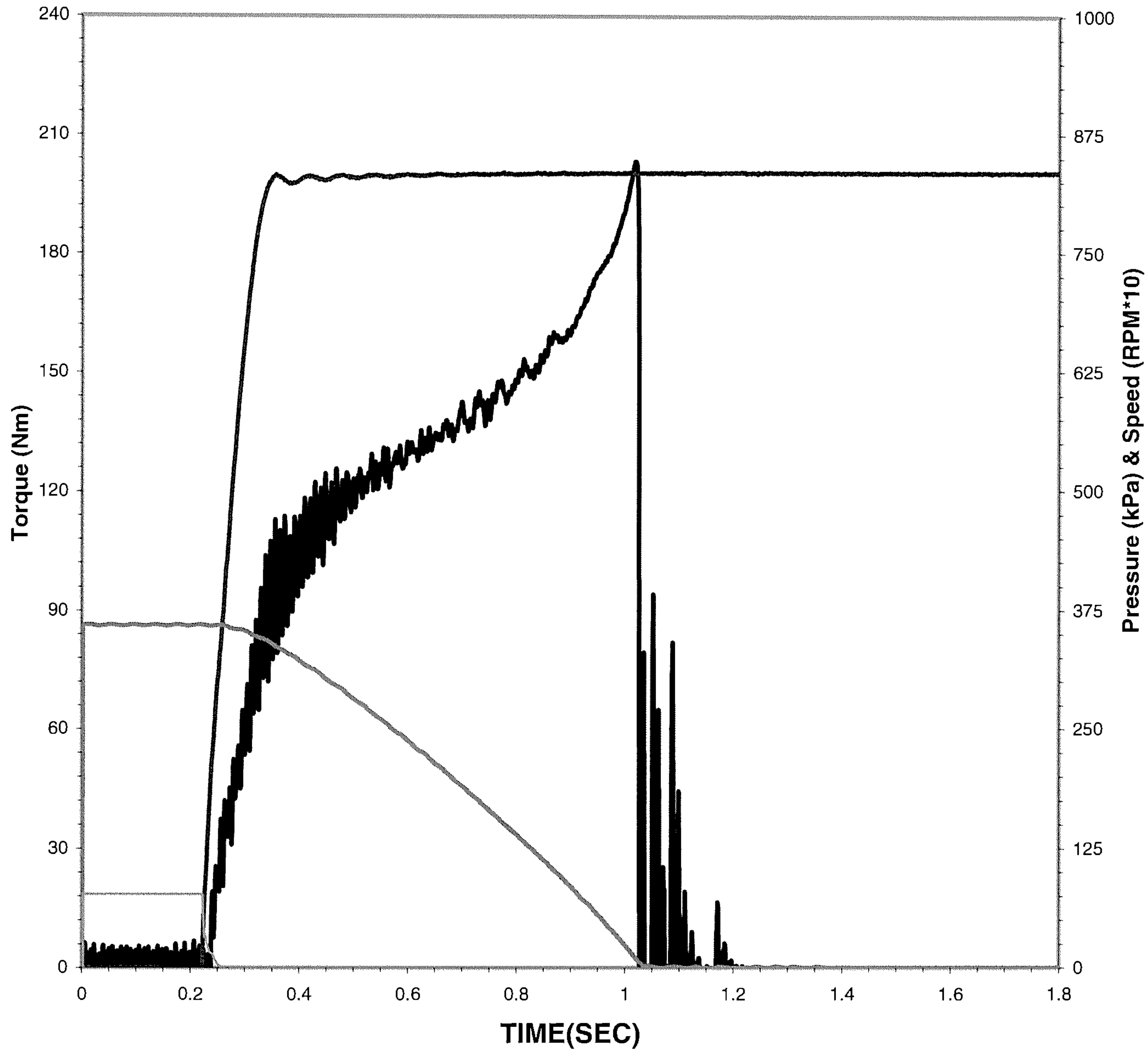
0.2 Sec Dyn:	114 N*m
Midpoint Dyn:	136 N*m
LwSpd Dynamic:	196 N*m

Coefficient of Friction

.2 Sec Dyn:	0.079
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.135

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: **10/15/2011**

Time of Test: **1:35:02**

Test Number: **C4-4-1342**

Fluid Code: **LO271510**

Cycle Number: **2001**

Temperature: **106.1 °C**
(112.7 ± 3.0 °C)

Apply Pressure: **832 kPa**
827 ± 7 KPa)

Apply Rate: **0.13 Sec**
(0.15 ± 0.02 Sec)

Energy: **18.4 KJ**
(18.71 ± 0.40 KJ)

Engage Time: **0.805 Sec**

Torque

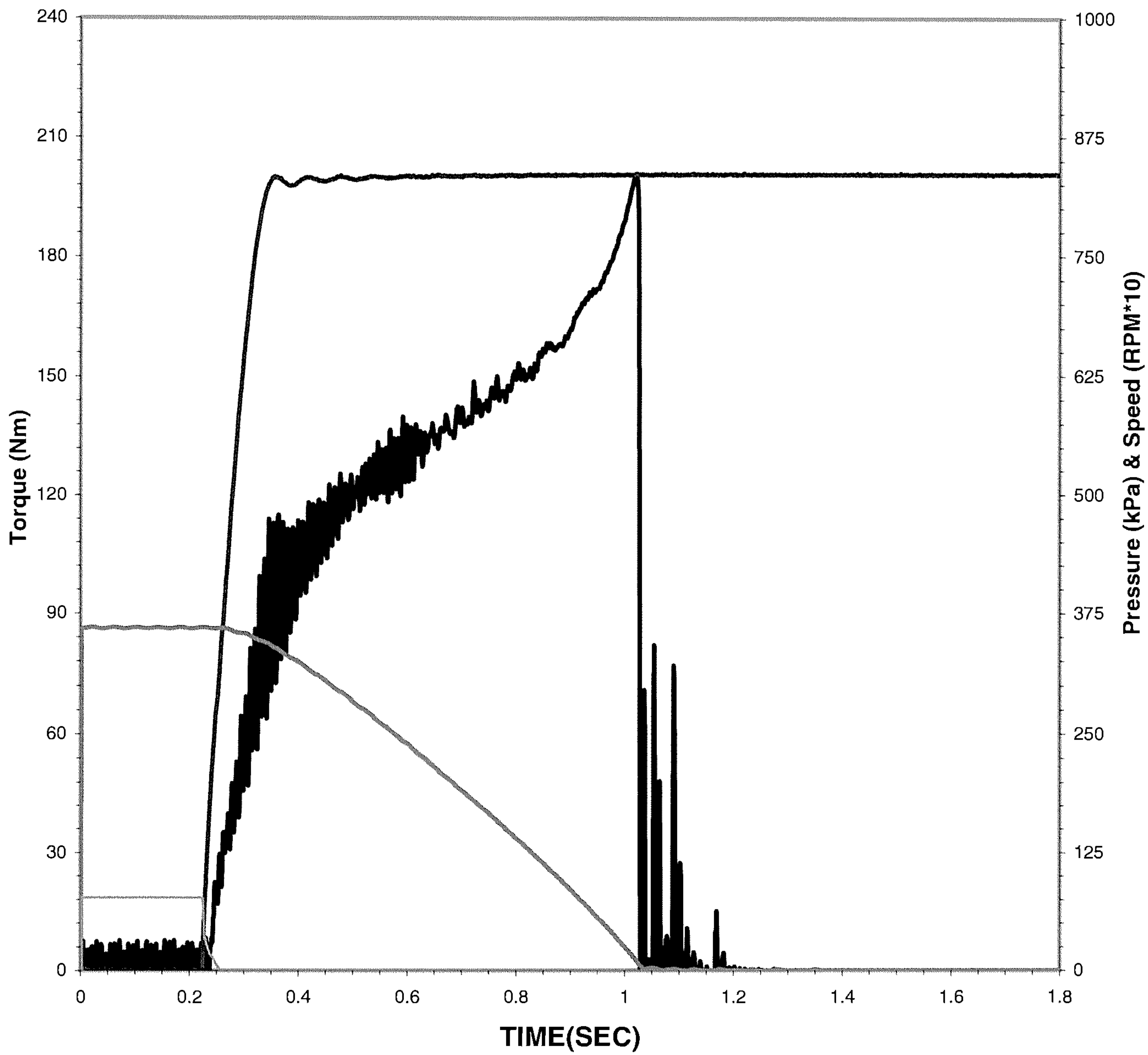
0.2 Sec Dyn: **110 N*m**
Midpoint Dyn: **132 N*m**
LwSpd Dynamic: **198 N*m**

Coefficient of Friction

.2 Sec Dyn: **0.076**
Midpoint Dyn: **0.091**
LwSpd Dynamic: **0.136**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	3:39:33
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	2499
Temperature:	110.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.805 Sec

Torque

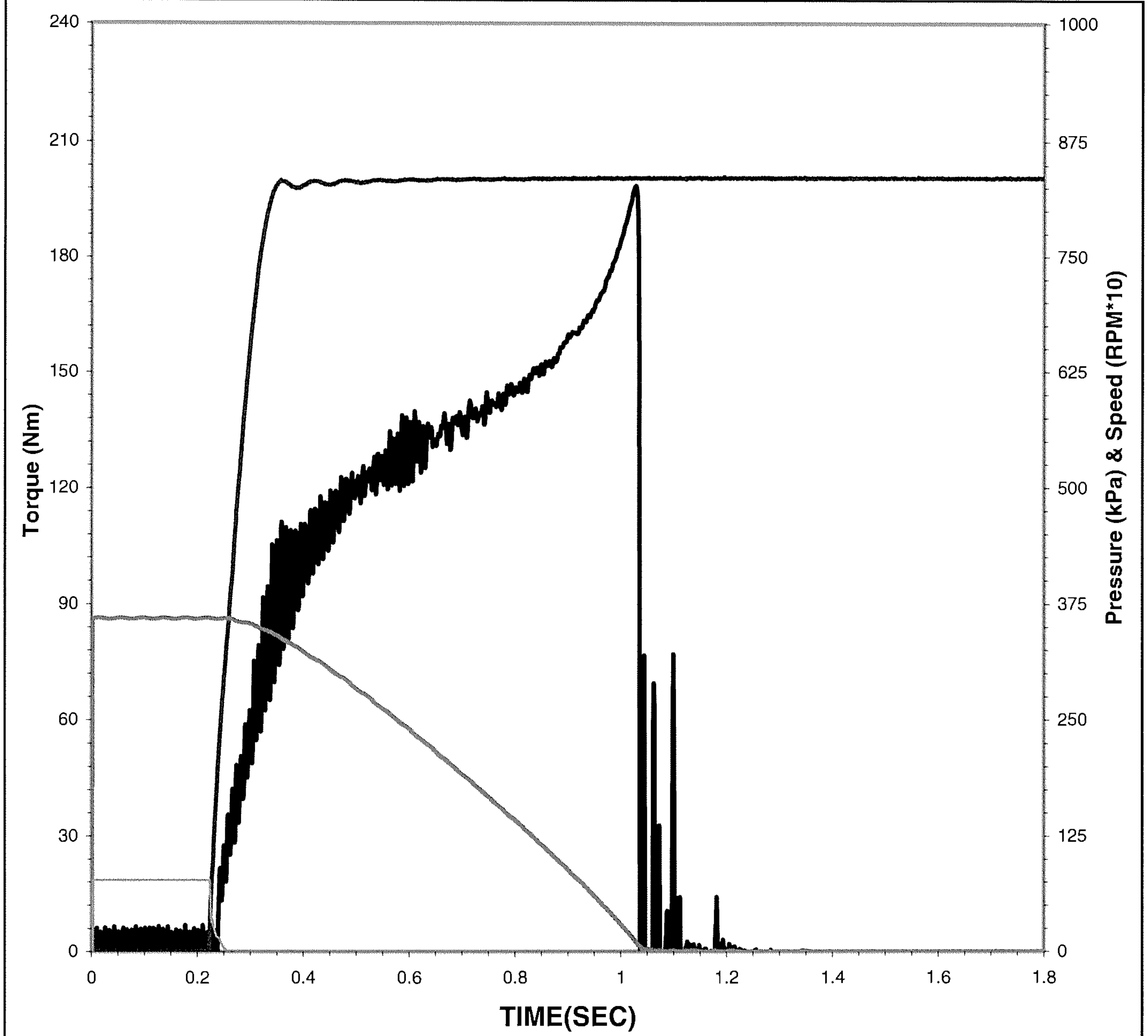
0.2 Sec Dyn:	110 N*m
Midpoint Dyn:	133 N*m
LwSpd Dynamic:	196 N*m

Coefficient of Friction

.2 Sec Dyn:	0.076
Midpoint Dyn:	0.092
LwSpd Dynamic:	0.135

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	3:39:48
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	2500
Temperature:	110.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.814 Sec

Torque

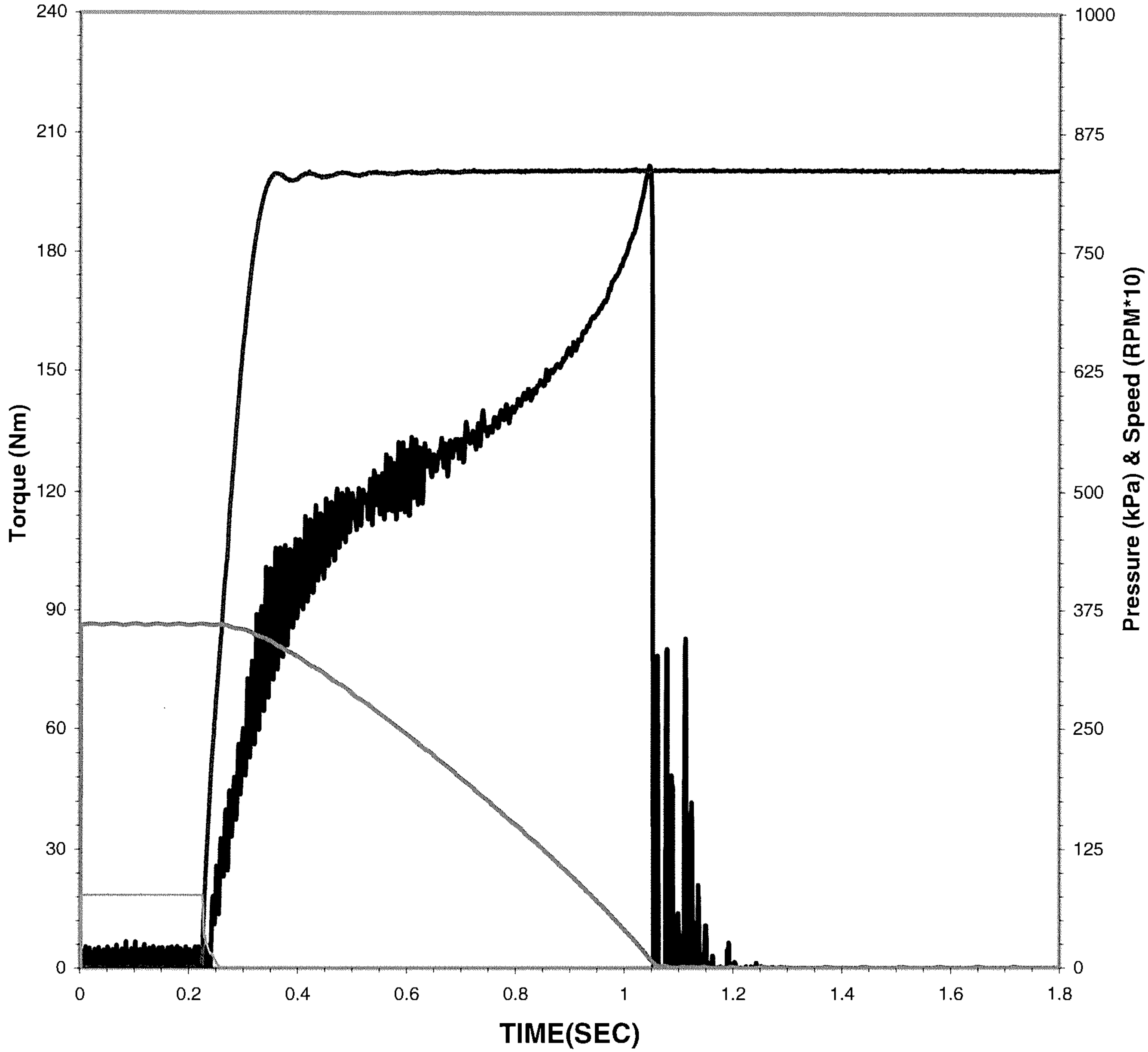
0.2 Sec Dyn:	107 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	191 N*m

Coefficient of Friction

.2 Sec Dyn:	0.074
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.132

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 10/15/2011

Time of Test: 3:40:14

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 2501

Temperature: 106.0 °C
(112.7 ± 3.0 °C)

Apply Pressure: 833 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.829 Sec

Torque

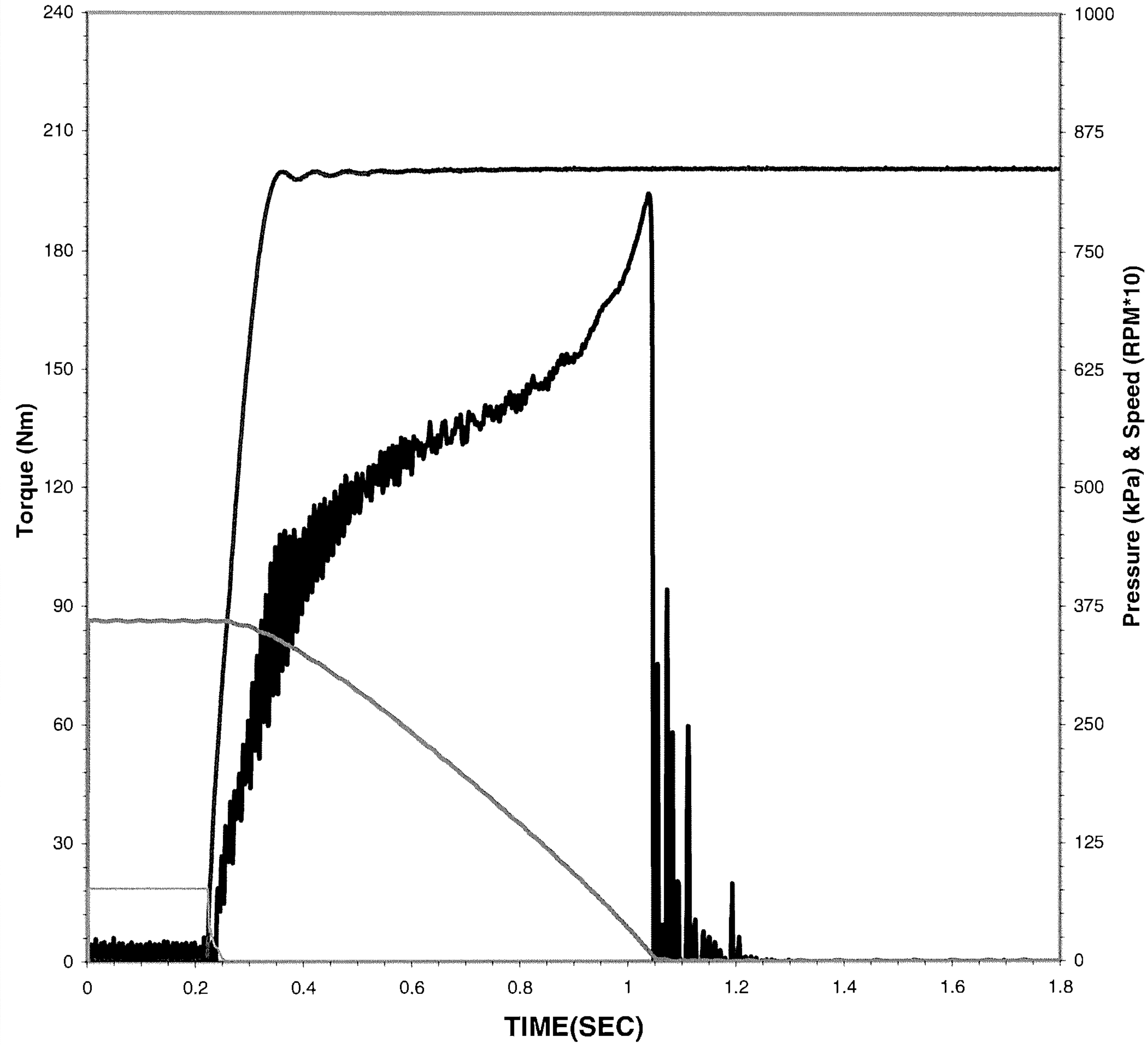
0.2 Sec Dyn: 105 N*m
Midpoint Dyn: 127 N*m
LwSpd Dynamic: 198 N*m

Coefficient of Friction

.2 Sec Dyn: 0.073
Midpoint Dyn: 0.088
LwSpd Dynamic: 0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	5:44:44
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	2999
Temperature:	110.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.825 Sec

Torque

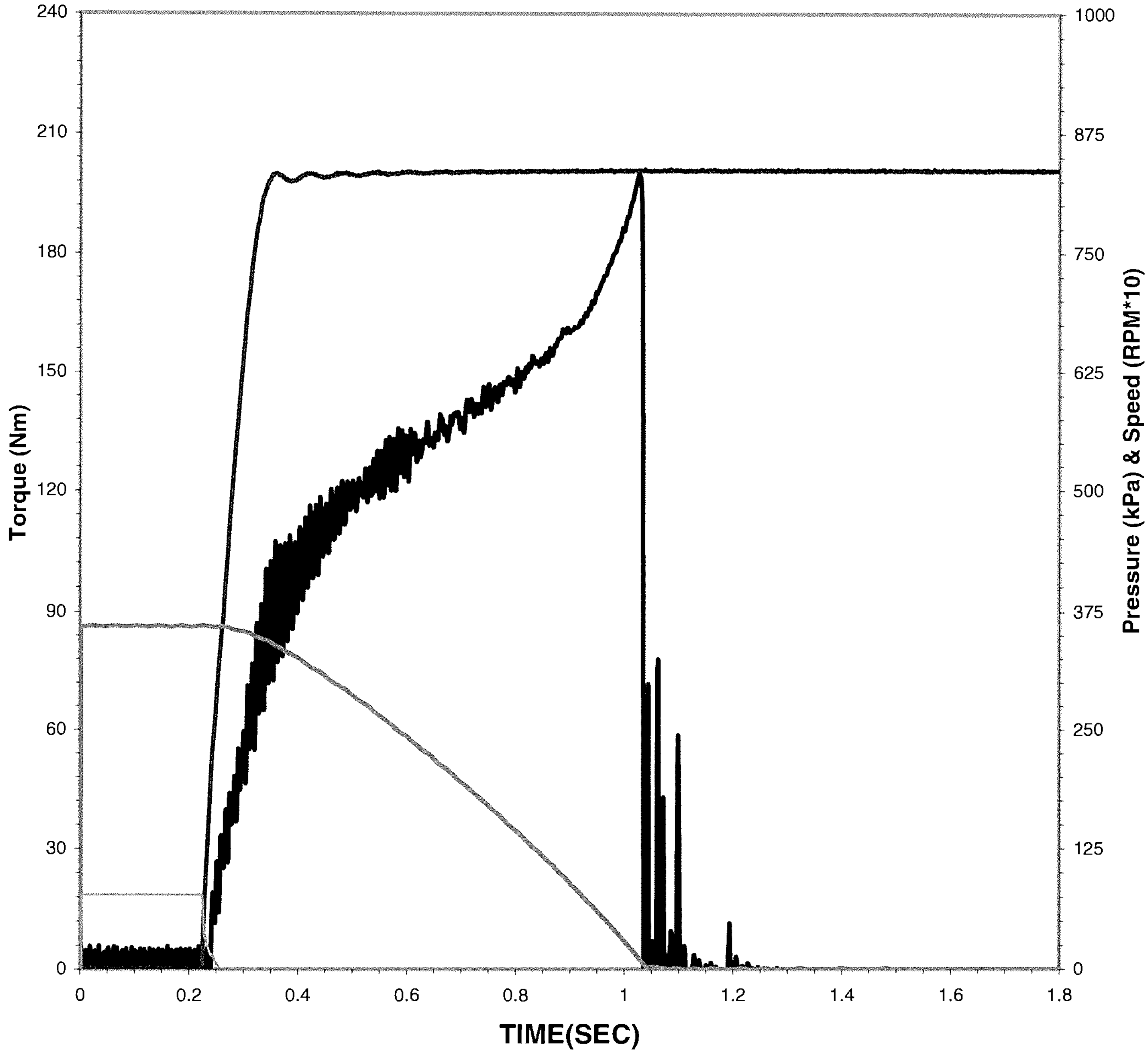
0.2 Sec Dyn:	106 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	188 N*m

Coefficient of Friction

.2 Sec Dyn:	0.073
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.130

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	5:44:59
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	3000
Temperature:	110.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.811 Sec

Torque

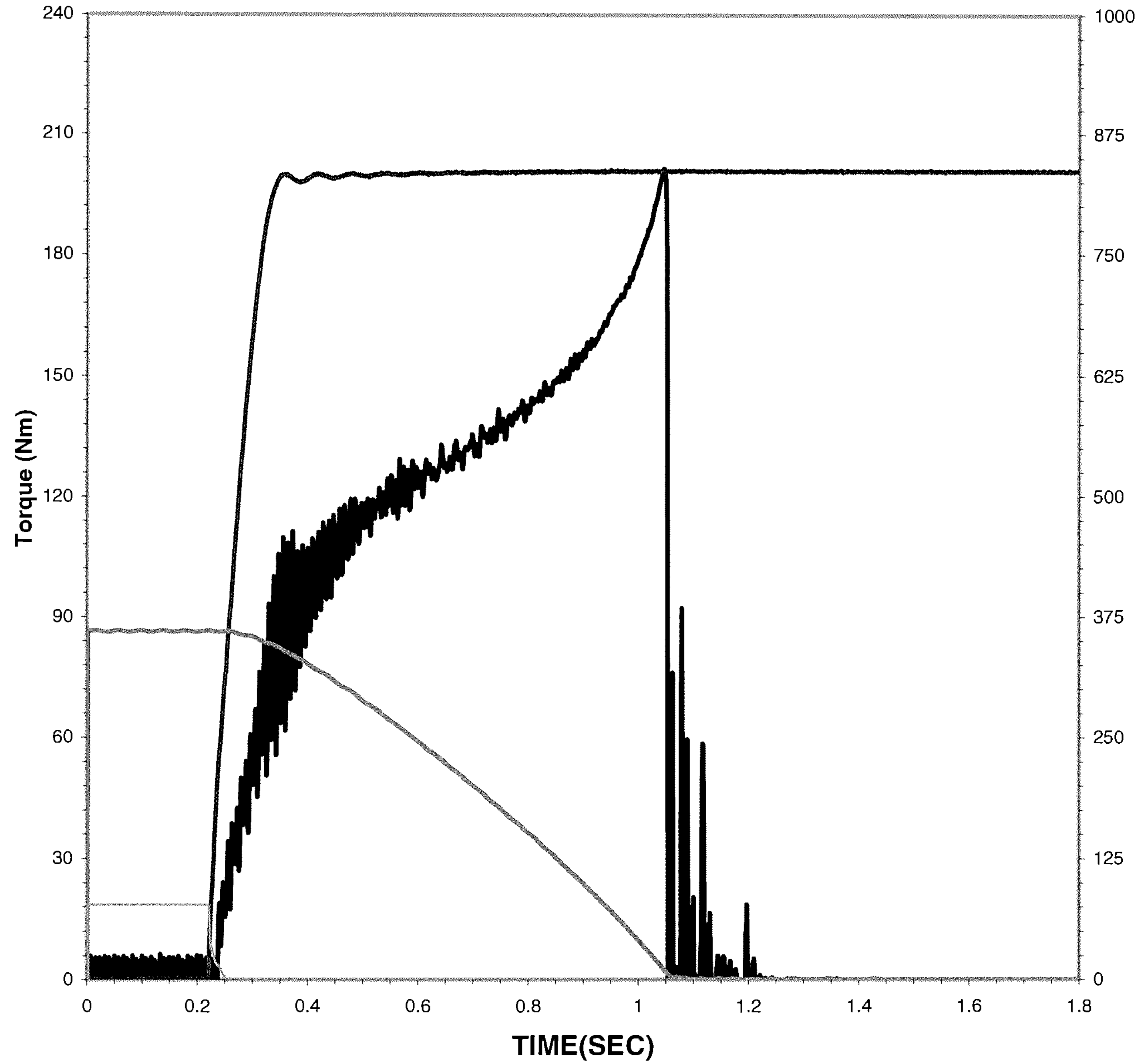
0.2 Sec Dyn:	107 N*m
Midpoint Dyn:	133 N*m
LwSpd Dynamic:	196 N*m

Coefficient of Friction

.2 Sec Dyn:	0.074
Midpoint Dyn:	0.092
LwSpd Dynamic:	0.136

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	5:45:26
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	3001
Temperature:	**106.1 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**833 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.5 KJ** (18.71 ± 0.40 KJ)
Engage Time:	0.833 Sec

Torque

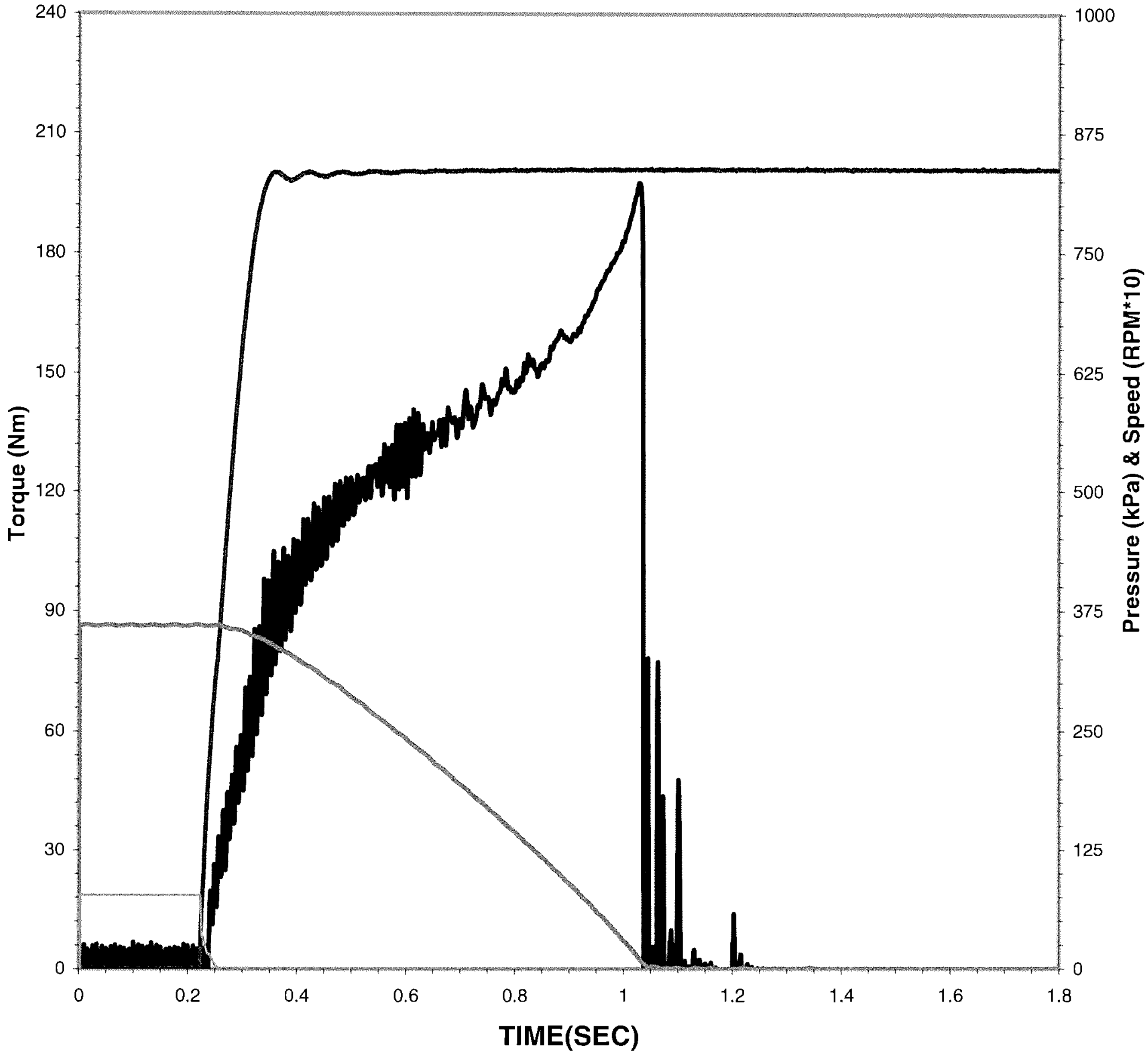
0.2 Sec Dyn:	102 N*m
Midpoint Dyn:	128 N*m
LwSpd Dynamic:	195 N*m

Coefficient of Friction

.2 Sec Dyn:	0.071
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.135

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	7:49:56
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	3499
Temperature:	110.8 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	833 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.815 Sec

Torque

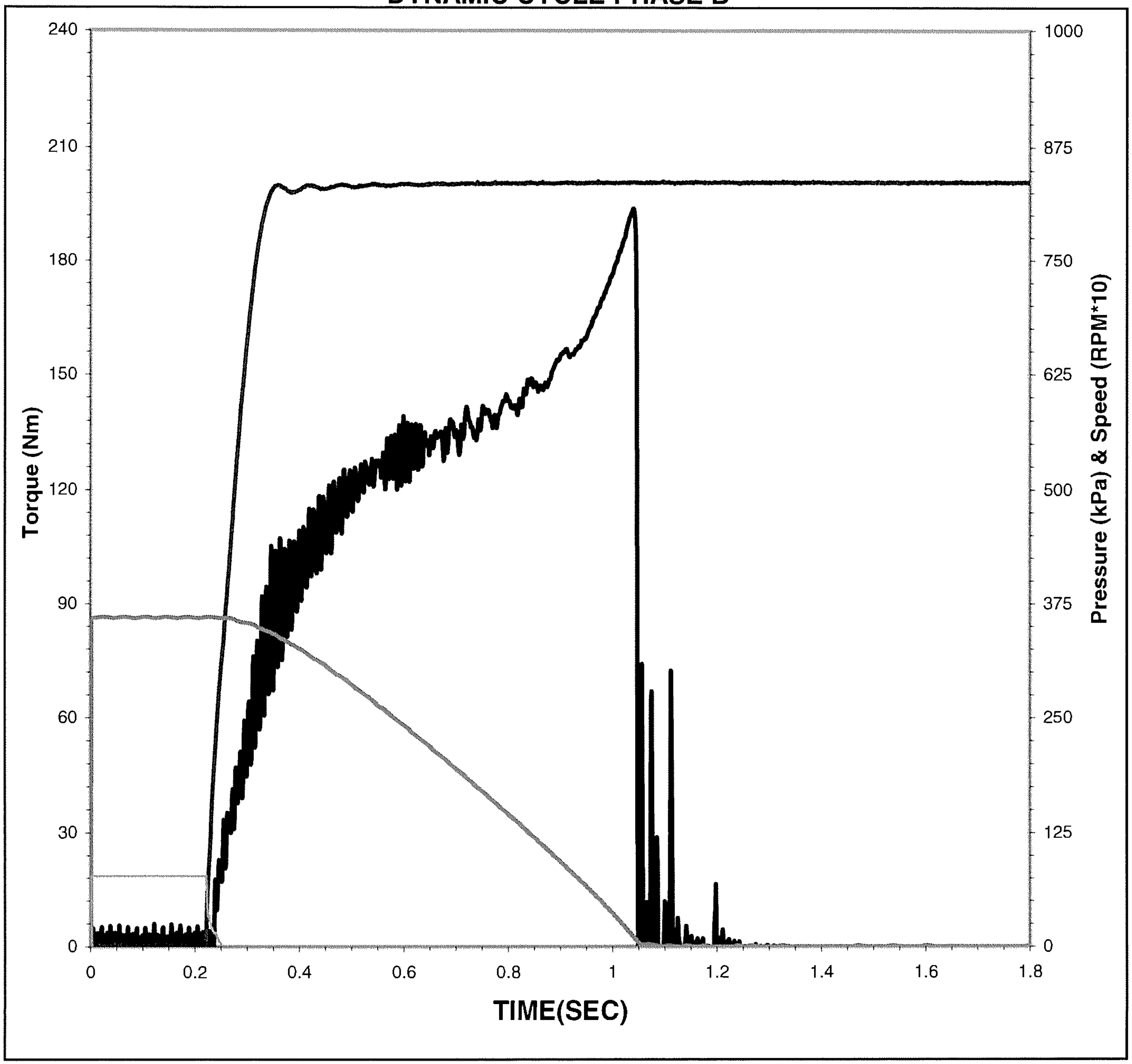
0.2 Sec Dyn:	106 N*m
Midpoint Dyn:	133 N*m
LwSpd Dynamic:	192 N*m

Coefficient of Friction

.2 Sec Dyn:	0.073
Midpoint Dyn:	0.092
LwSpd Dynamic:	0.133

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	7:50:11
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	3500
Temperature:	**110.9 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**833 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	0.828 Sec

Torque

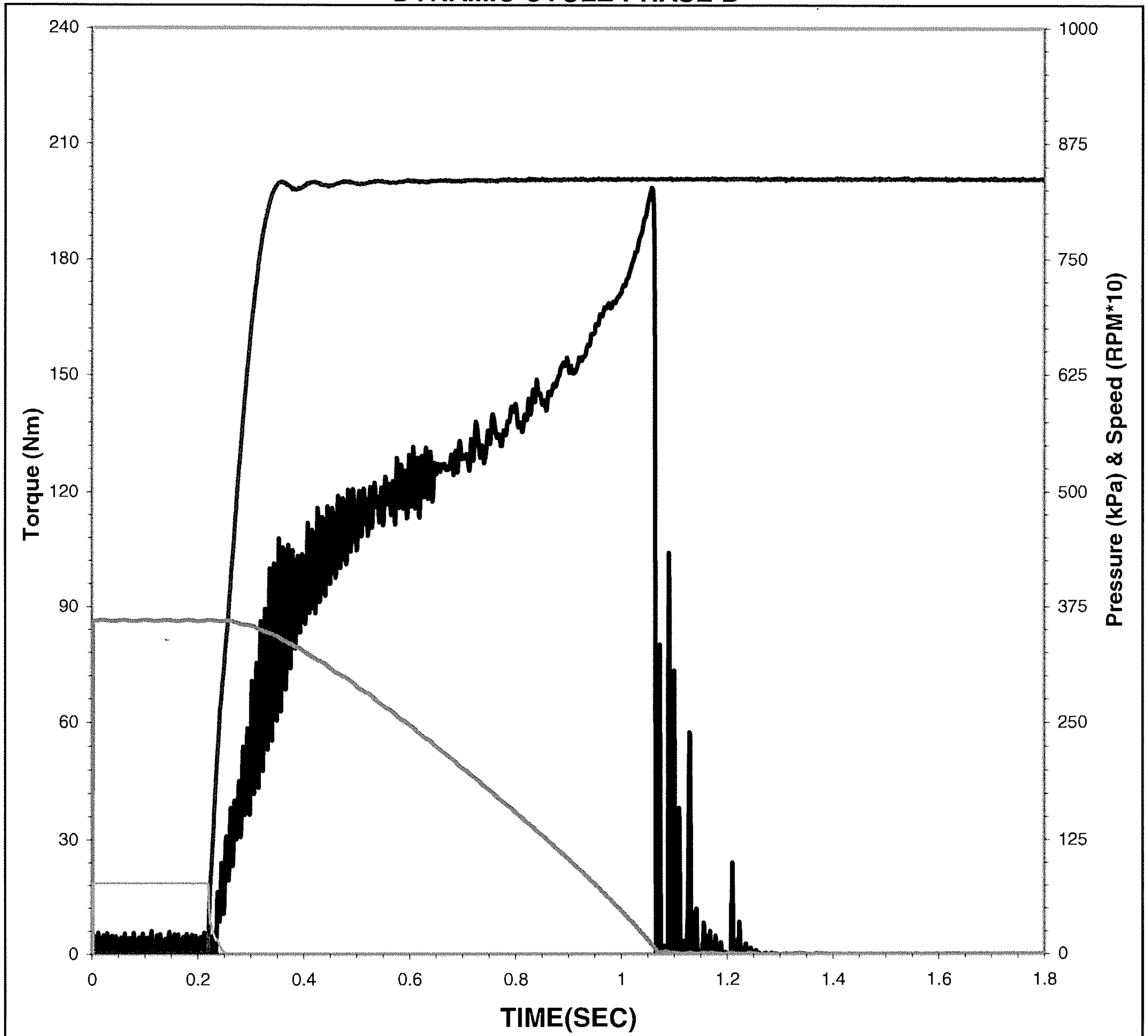
0.2 Sec Dyn:	106 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	188 N*m

Coefficient of Friction

.2 Sec Dyn:	0.073
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.130

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	7:50:38
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	3501
Temperature:	106.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	834 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.846 Sec

Torque

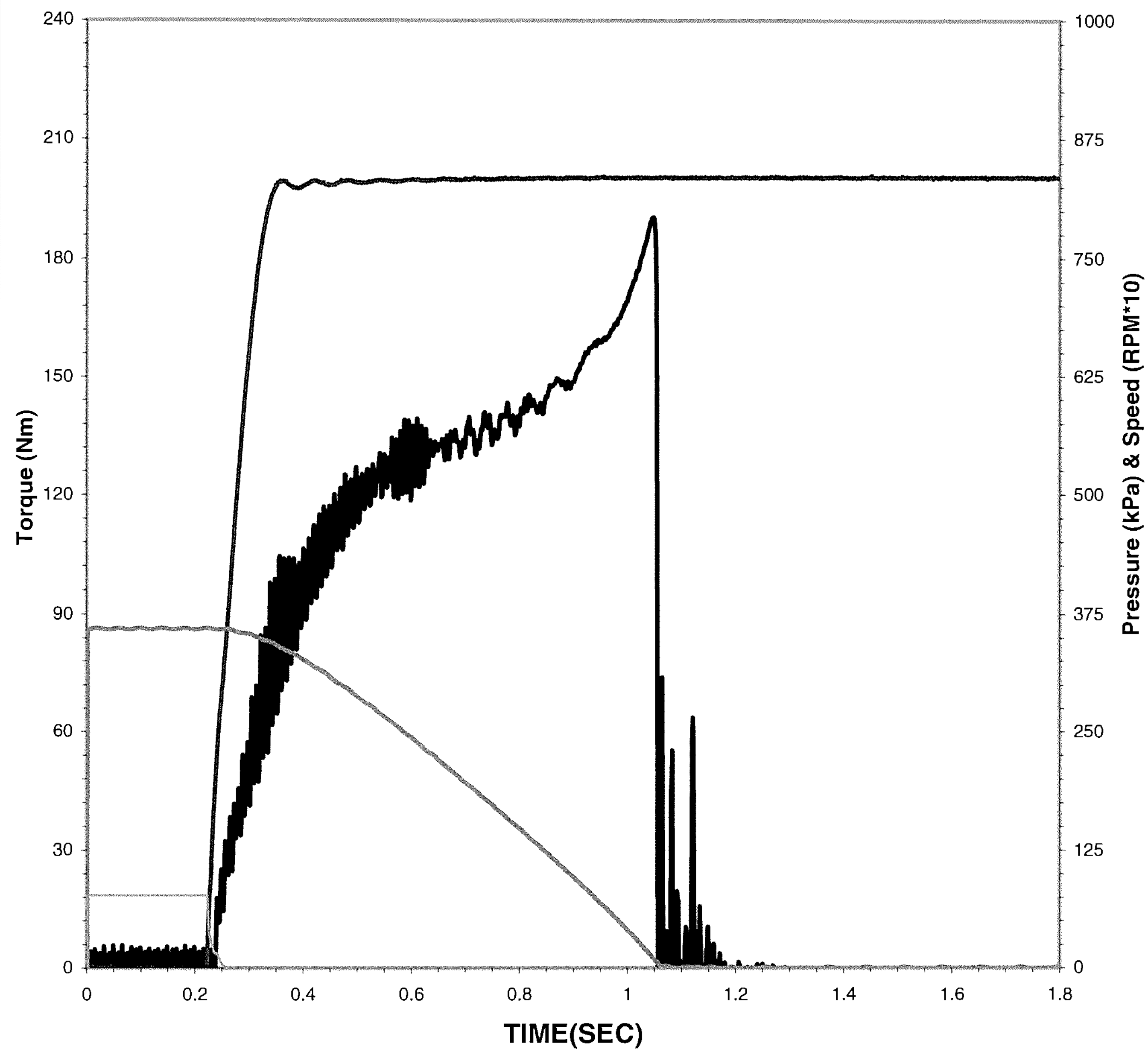
0.2 Sec Dyn:	102 N*m
Midpoint Dyn:	125 N*m
LwSpd Dynamic:	193 N*m

Coefficient of Friction

.2 Sec Dyn:	0.070
Midpoint Dyn:	0.086
LwSpd Dynamic:	0.133

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	9:55:08
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	3999
Temperature:	**110.7 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**832 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.833 Sec**

Torque

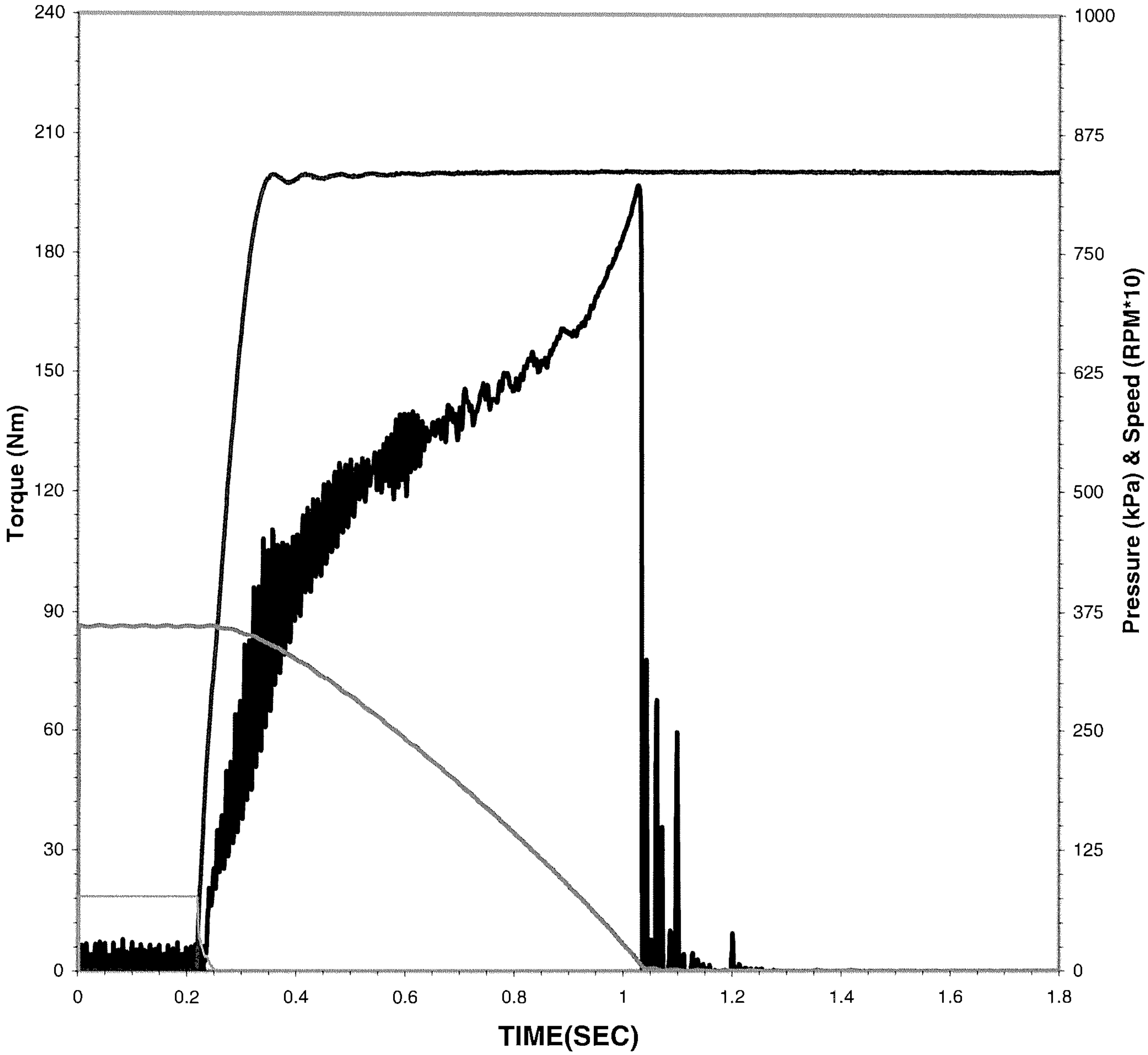
0.2 Sec Dyn:	105 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	183 N*m

Coefficient of Friction

.2 Sec Dyn:	0.073
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	9:55:23
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	4000
Temperature:	110.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.817 Sec

Torque

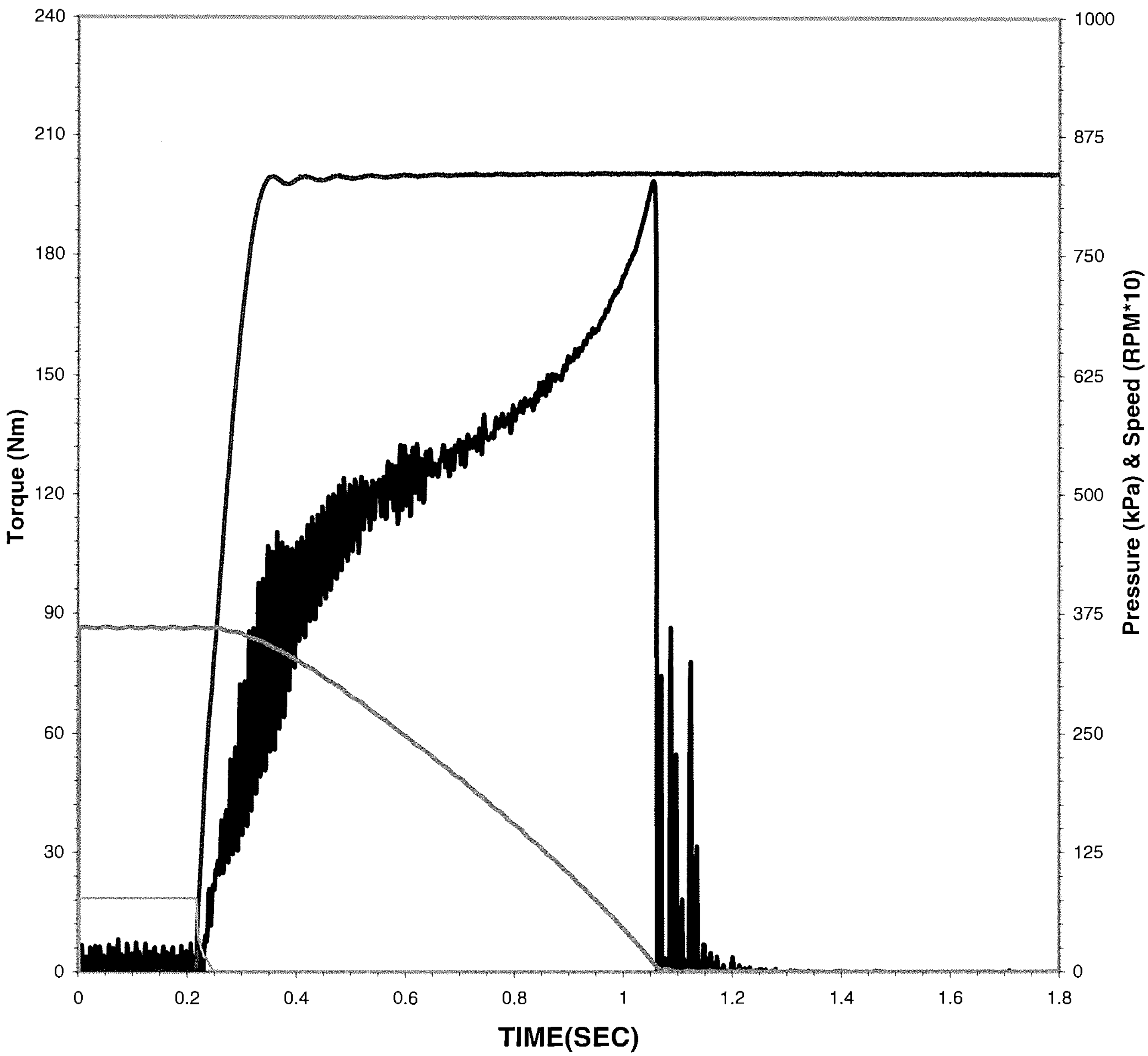
0.2 Sec Dyn:	104 N*m
Midpoint Dyn:	133 N*m
LwSpd Dynamic:	191 N*m

Coefficient of Friction

.2 Sec Dyn:	0.072
Midpoint Dyn:	0.092
LwSpd Dynamic:	0.132

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	9:55:50
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	4001
Temperature:	106.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.845 Sec

Torque

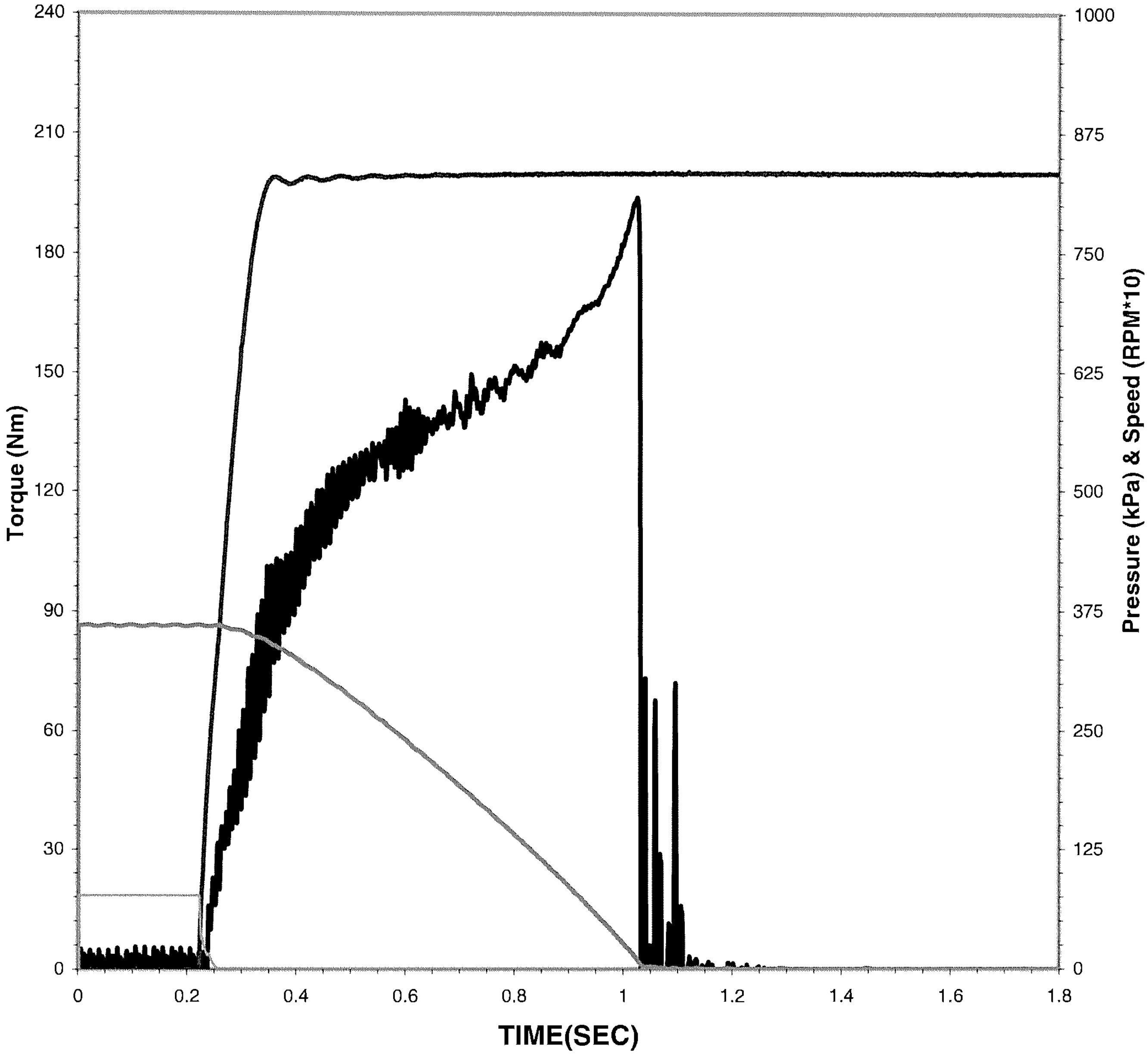
0.2 Sec Dyn:	98 N*m
Midpoint Dyn:	127 N*m
LwSpd Dynamic:	192 N*m

Coefficient of Friction

.2 Sec Dyn:	0.068
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.133

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	12:00:20
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	4499
Temperature:	110.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.81 Sec

Torque

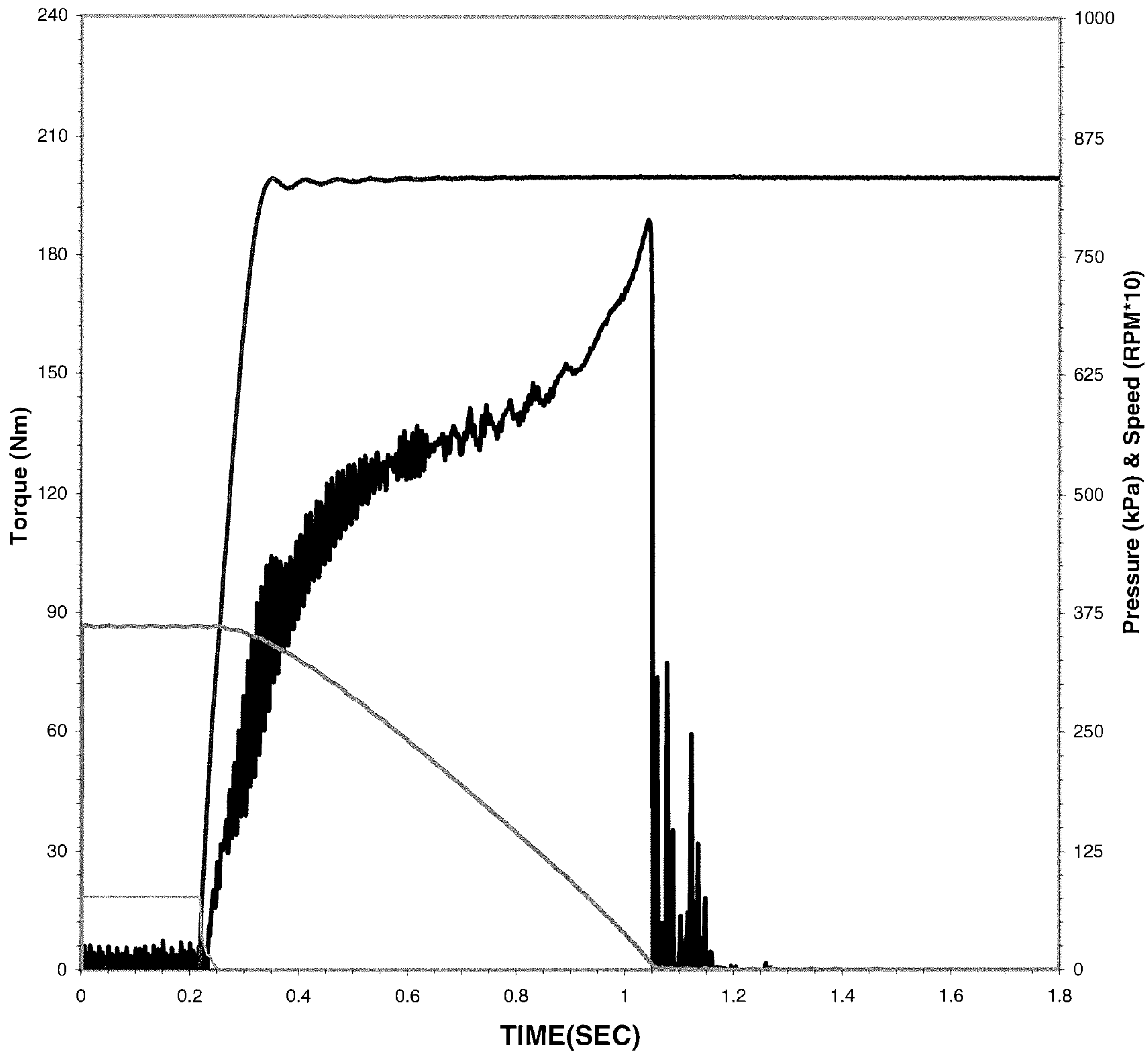
0.2 Sec Dyn:	109 N*m
Midpoint Dyn:	135 N*m
LwSpd Dynamic:	186 N*m

Coefficient of Friction

.2 Sec Dyn:	0.075
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.129

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	12:00:35
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	4500
Temperature:	110.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.833 Sec

Torque

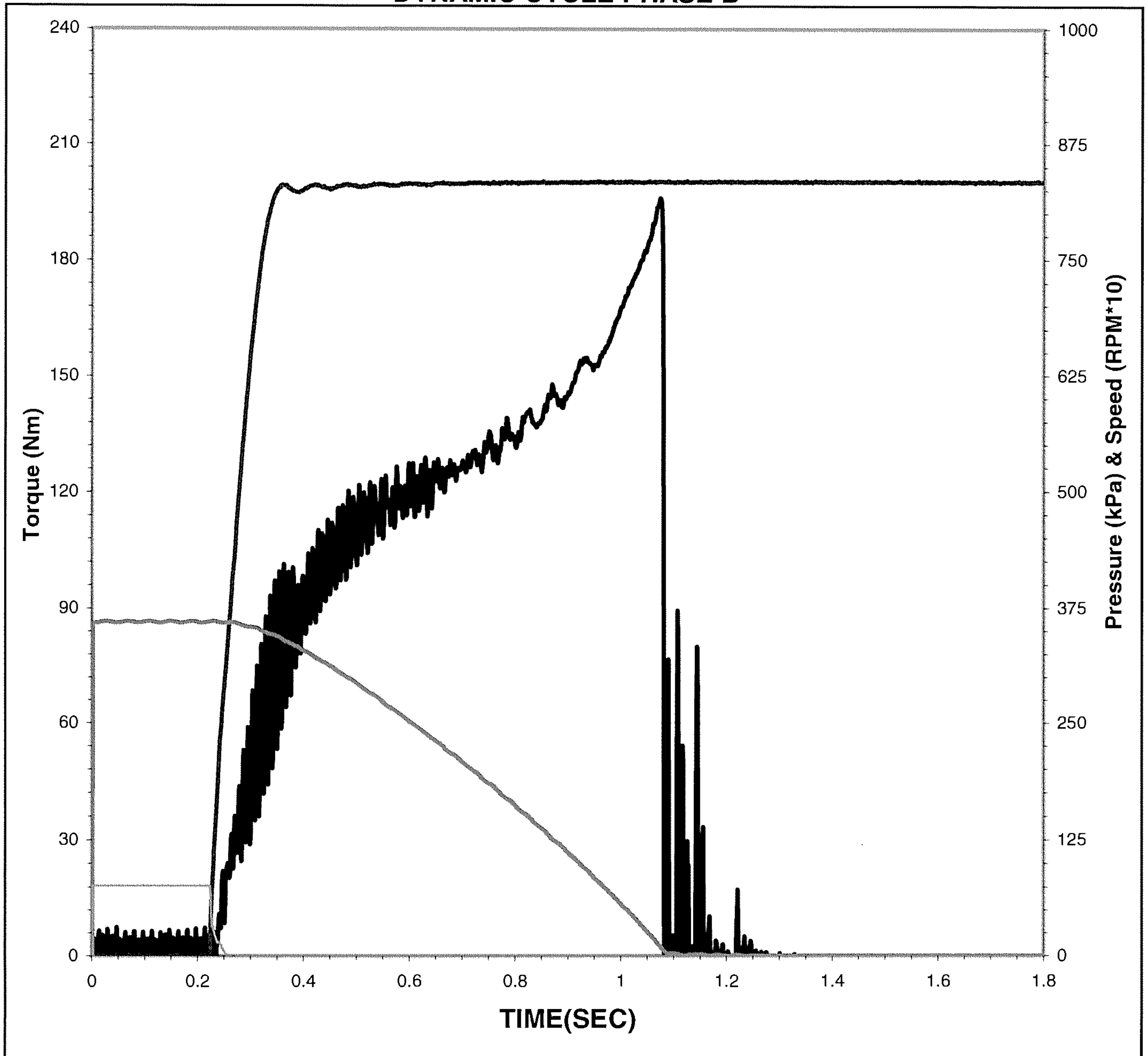
0.2 Sec Dyn:	106 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	182 N*m

Coefficient of Friction

.2 Sec Dyn:	0.073
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	12:01:01
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	4501
Temperature:	105.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.859 Sec

Torque

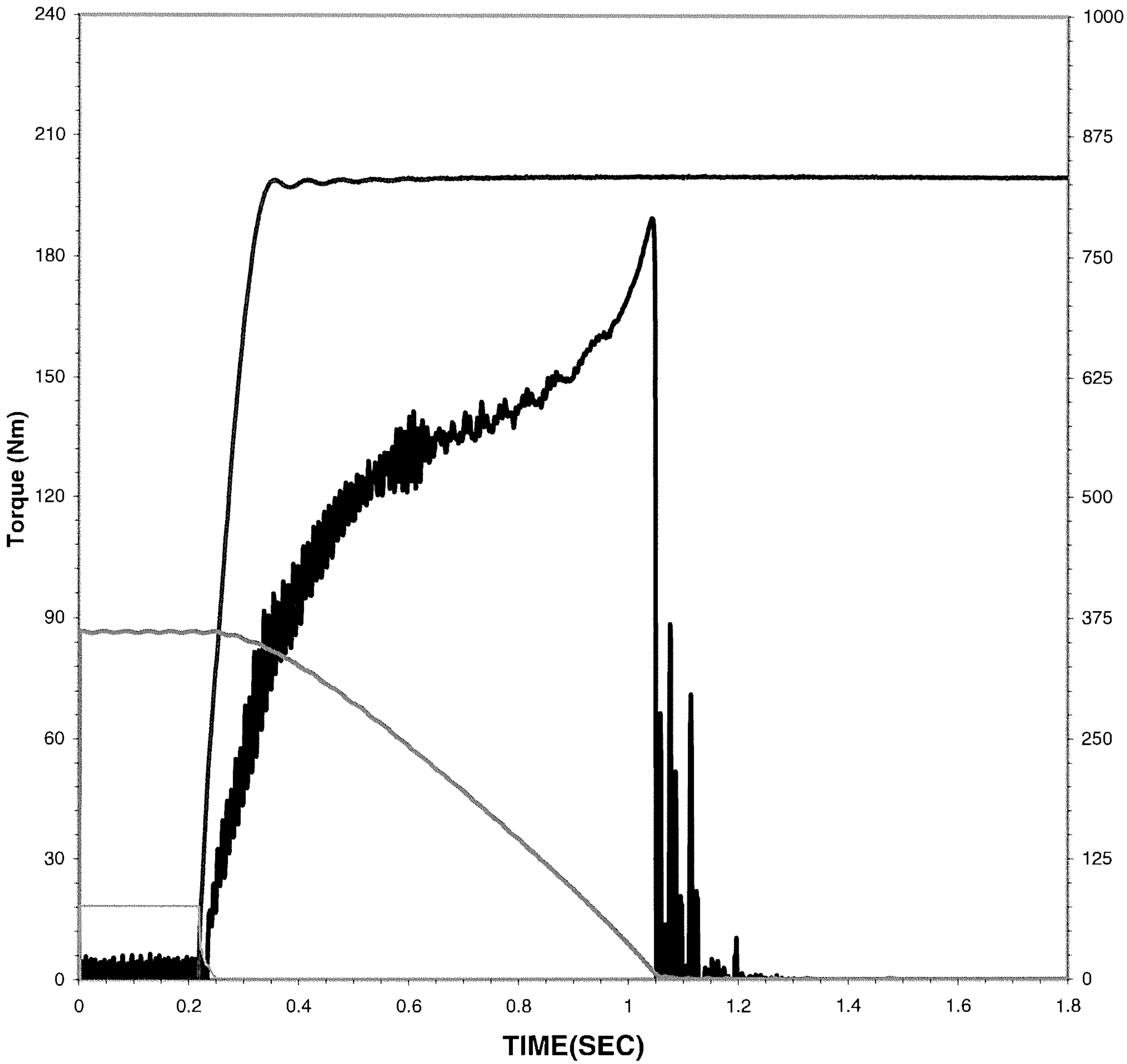
0.2 Sec Dyn:	98 N*m
Midpoint Dyn:	124 N*m
LwSpd Dynamic:	190 N*m

Coefficient of Friction

.2 Sec Dyn:	0.068
Midpoint Dyn:	0.086
LwSpd Dynamic:	0.131

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	14:05:32
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	4999
Temperature:	110.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.833 Sec

Torque

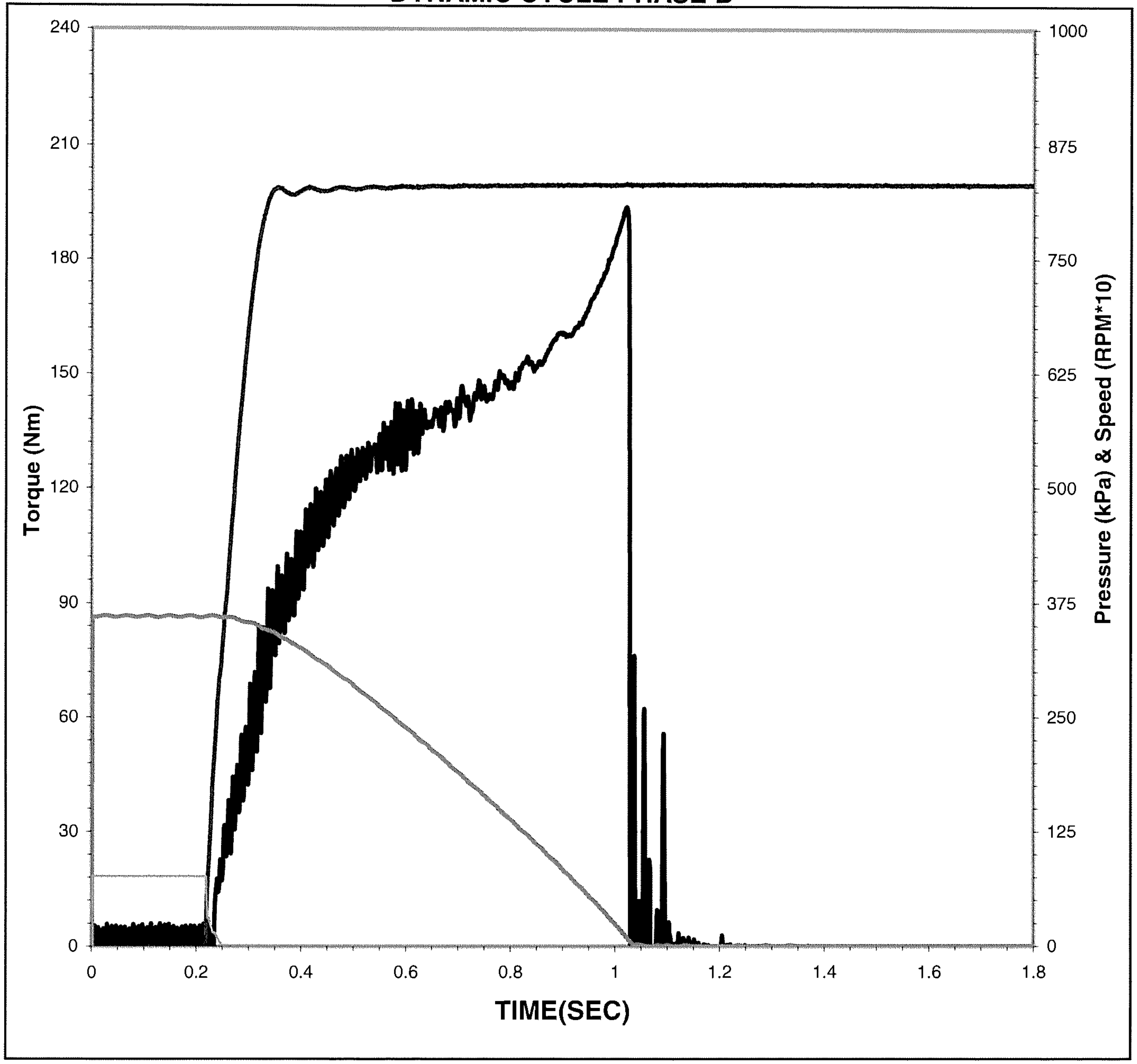
0.2 Sec Dyn:	102 N*m
Midpoint Dyn:	134 N*m
LwSpd Dynamic:	186 N*m

Coefficient of Friction

.2 Sec Dyn:	0.071
Midpoint Dyn:	0.092
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	14:05:47
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	5000
Temperature:	110.3 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.812 Sec

Torque

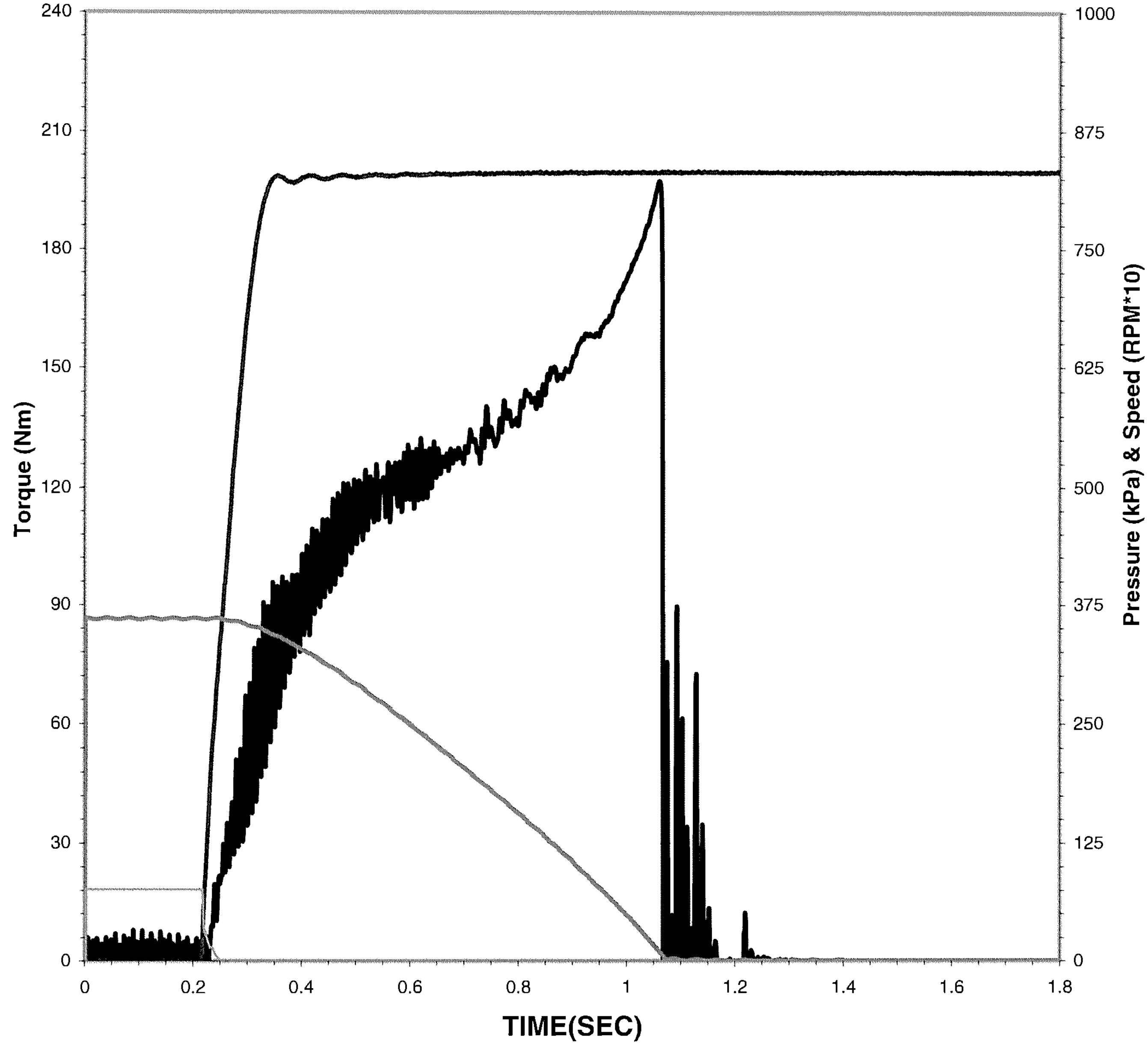
0.2 Sec Dyn:	107 N*m
Midpoint Dyn:	137 N*m
LwSpd Dynamic:	188 N*m

Coefficient of Friction

.2 Sec Dyn:	0.074
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.130

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	14:06:13
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	5001
Temperature:	106.0 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	830 kPa
	827 ± 7 KPa)
Apply Rate:	0.14 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.5 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.851 Sec

Torque

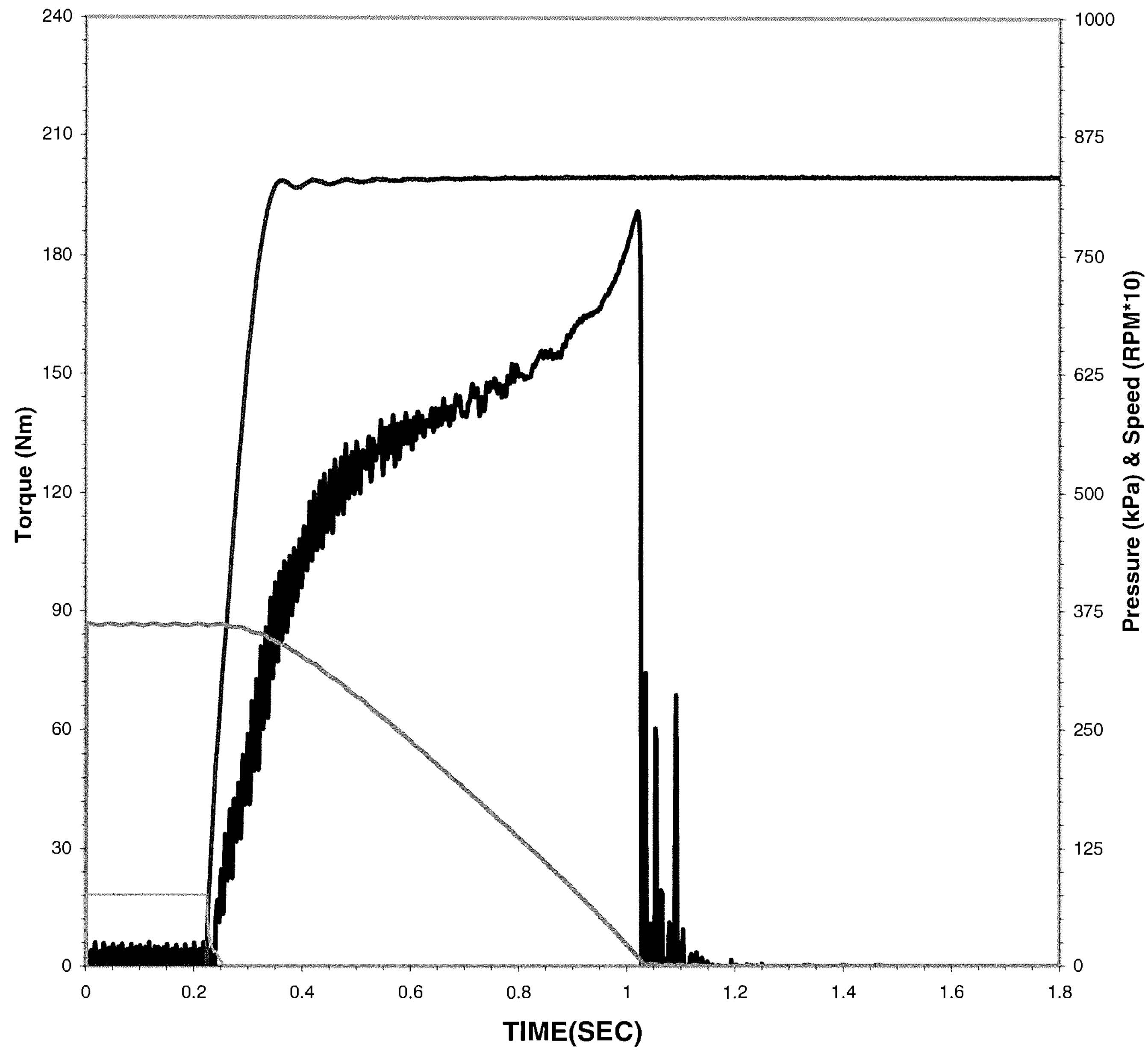
0.2 Sec Dyn:	96 N*m
Midpoint Dyn:	126 N*m
LwSpd Dynamic:	194 N*m

Coefficient of Friction

.2 Sec Dyn:	0.066
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.134

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 10/15/2011

Time of Test: 16:10:28

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 5498

Temperature: 110.5 °C
(112.7 ± 3.0 °C)

Apply Pressure: 829 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.804 Sec

Torque

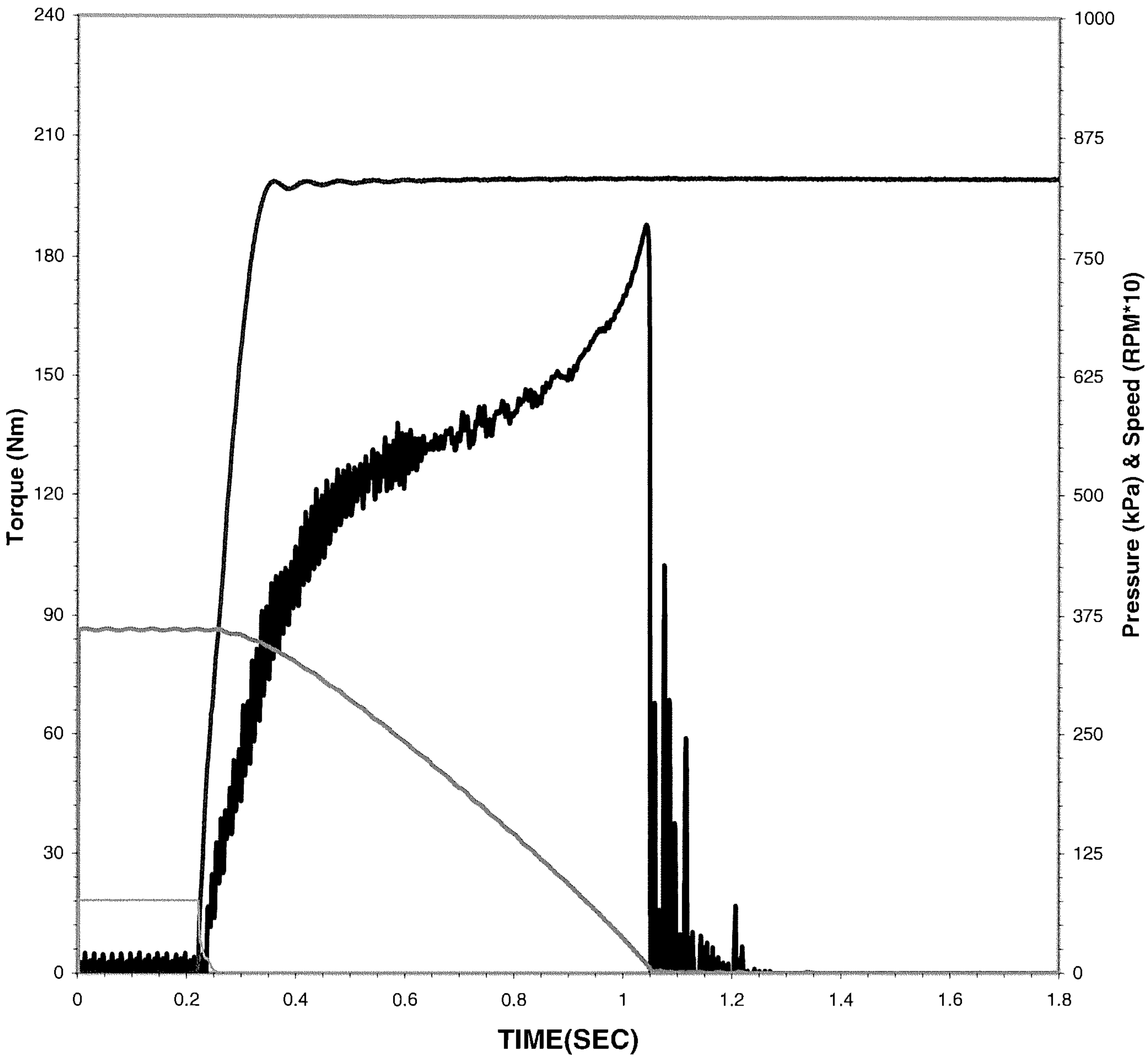
0.2 Sec Dyn:	112 N*m
Midpoint Dyn:	138 N*m
LwSpd Dynamic:	185 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	16:10:43
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	5499
Temperature:	110.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.83 Sec

Torque

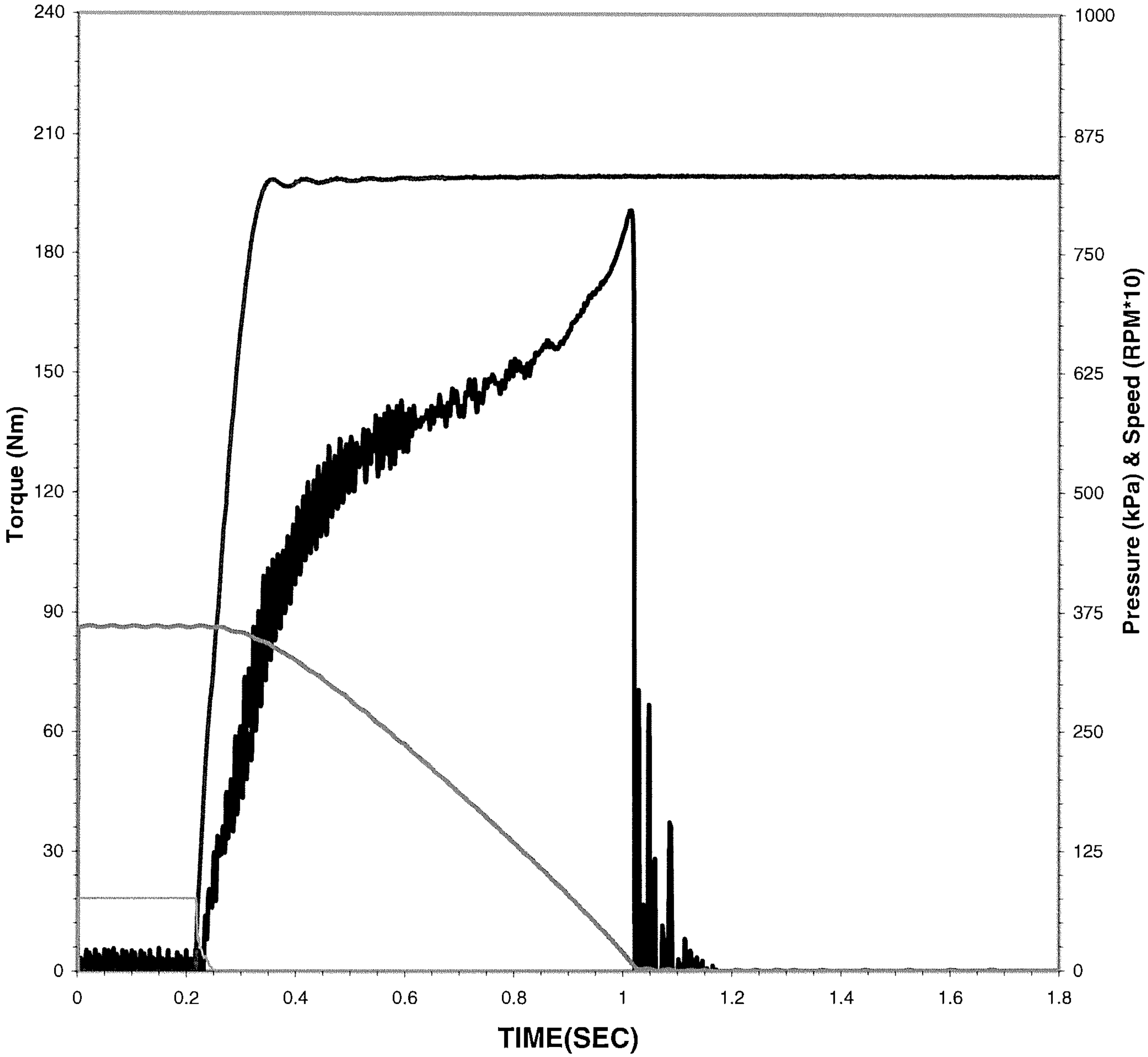
0.2 Sec Dyn:	108 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	184 N*m

Coefficient of Friction

.2 Sec Dyn:	0.074
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	10/15/2011
Time of Test:	16:10:59
Test Number:	C4-4-1342
Fluid Code:	LO271510
Cycle Number:	5500
Temperature:	110.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.804 Sec

Torque

0.2 Sec Dyn:	113 N*m
Midpoint Dyn:	138 N*m
LwSpd Dynamic:	187 N*m

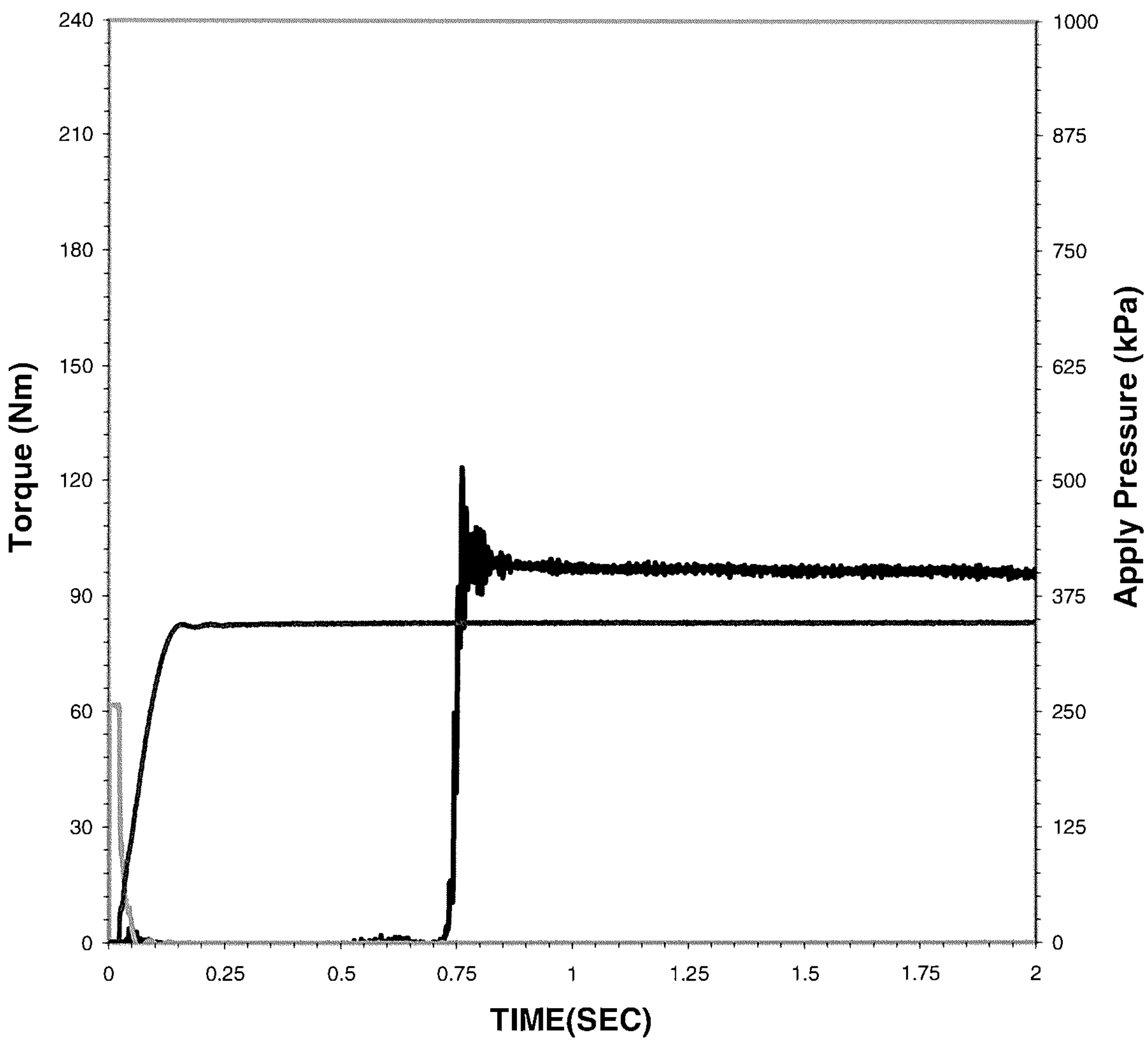
Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.129

STATIC TRACES

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 16:27:12

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 10

PHASE A

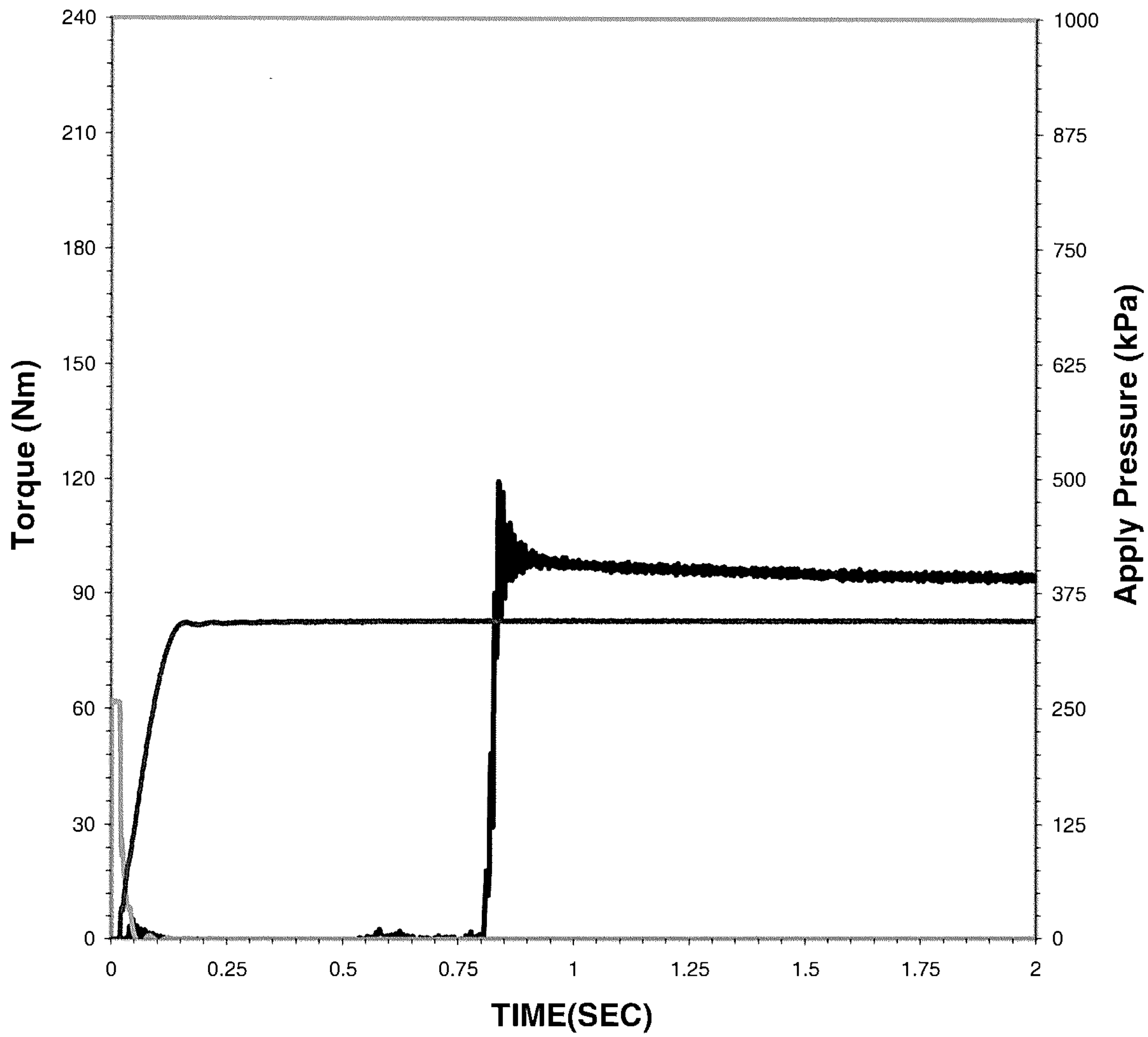
Apply Pressure:
At .25 Second: 345 kPa

Torque
Static Peak: 124 Nm
.25 Second: 98 Nm

Coefficient of Friction
Static Peak: 0.205
.25 Second: 0.163

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 18:29:54

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 500

PHASE A

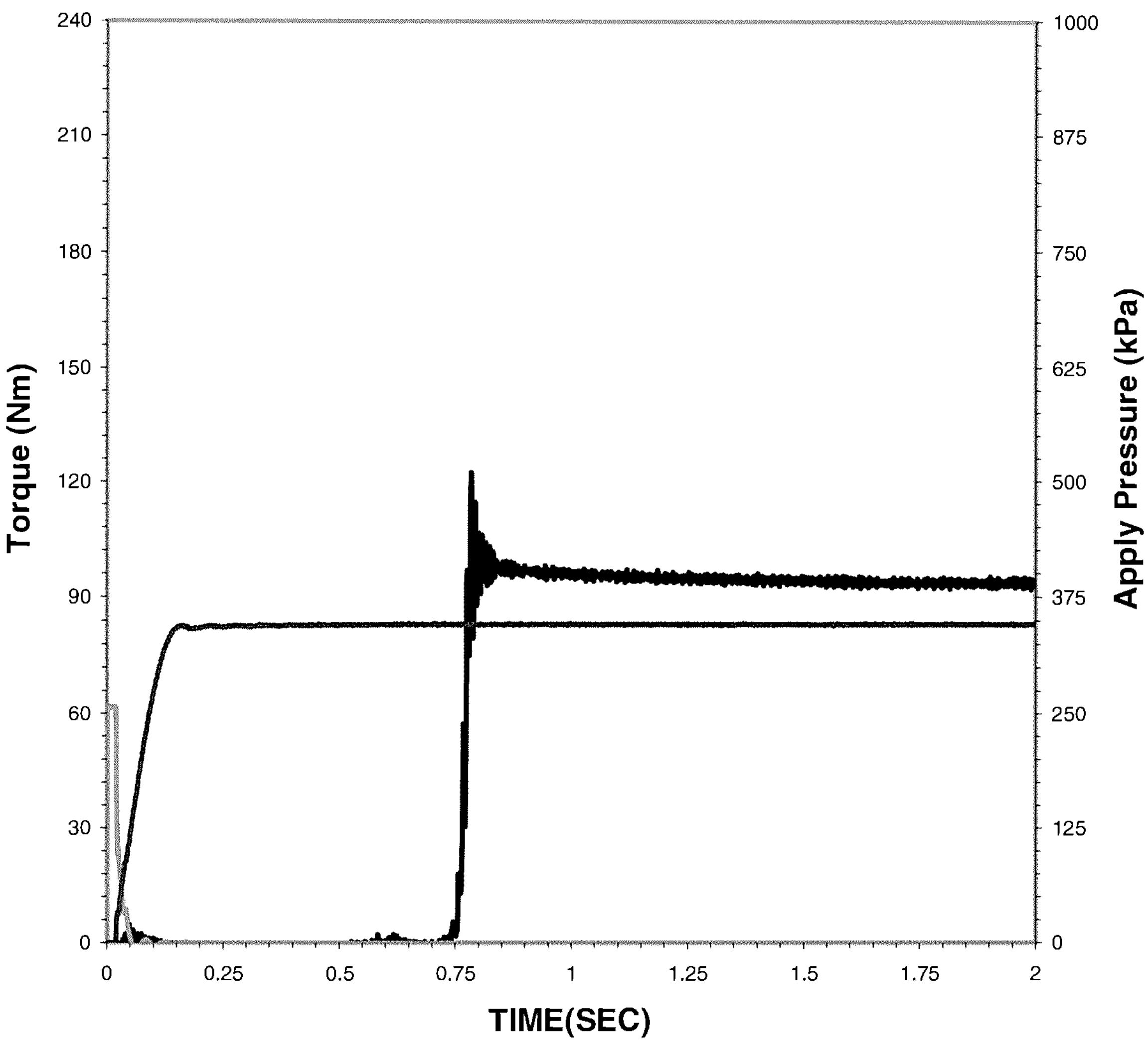
Apply Pressure:
At .25 Second: 346 kPa

Torque
Static Peak: 120 Nm
.25 Second: 98 Nm

Coefficient of Friction
Static Peak: 0.199
.25 Second: 0.163

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 20:35:06

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 1000

PHASE A

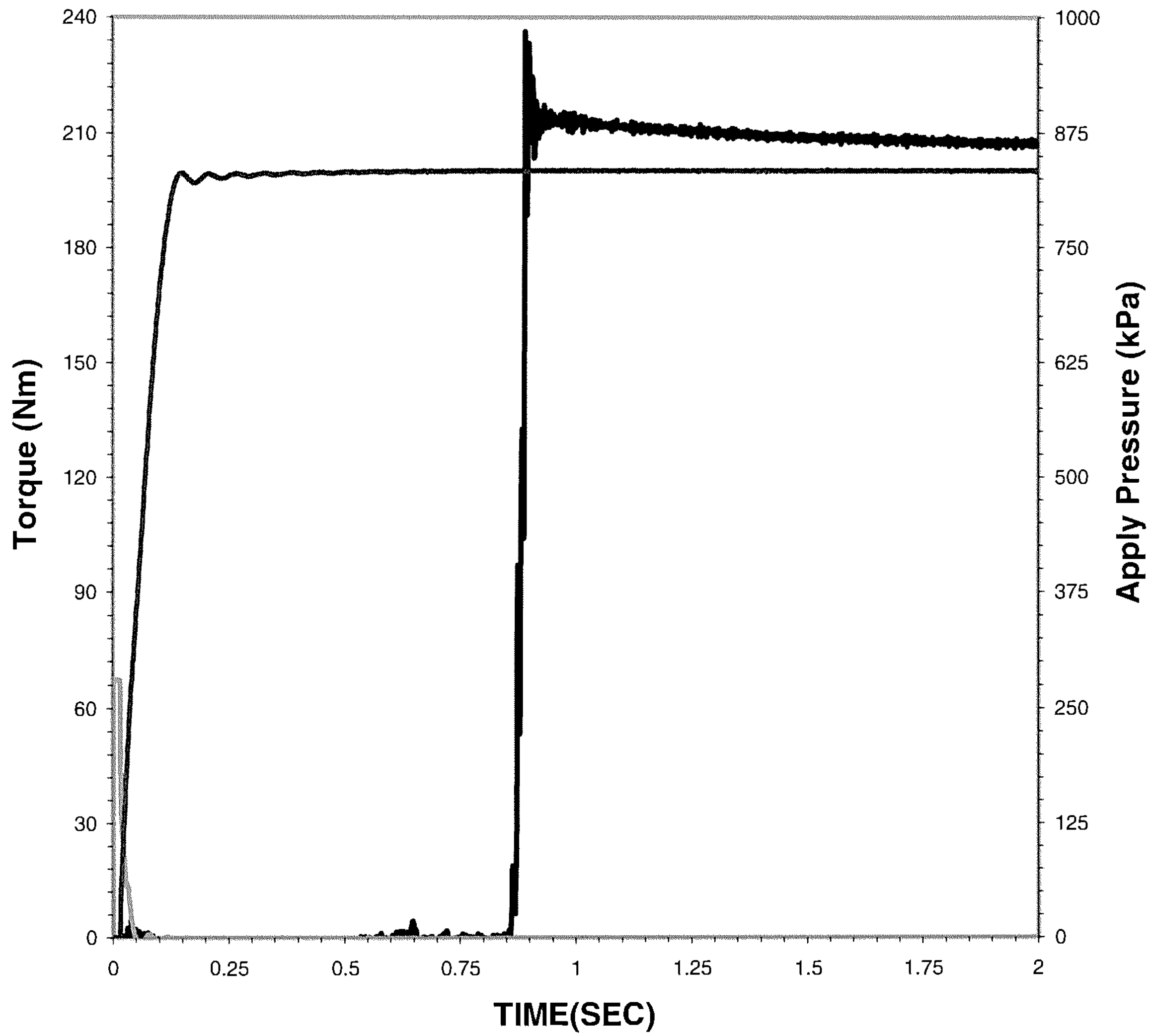
Apply Pressure:
At .25 Second: 346 kPa

Torque
Static Peak: 123 Nm
.25 Second: 96 Nm

Coefficient of Friction
Static Peak: 0.204
.25 Second: 0.160

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/14/2011

Time of Test: 23:29:36

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 1500

PHASE B

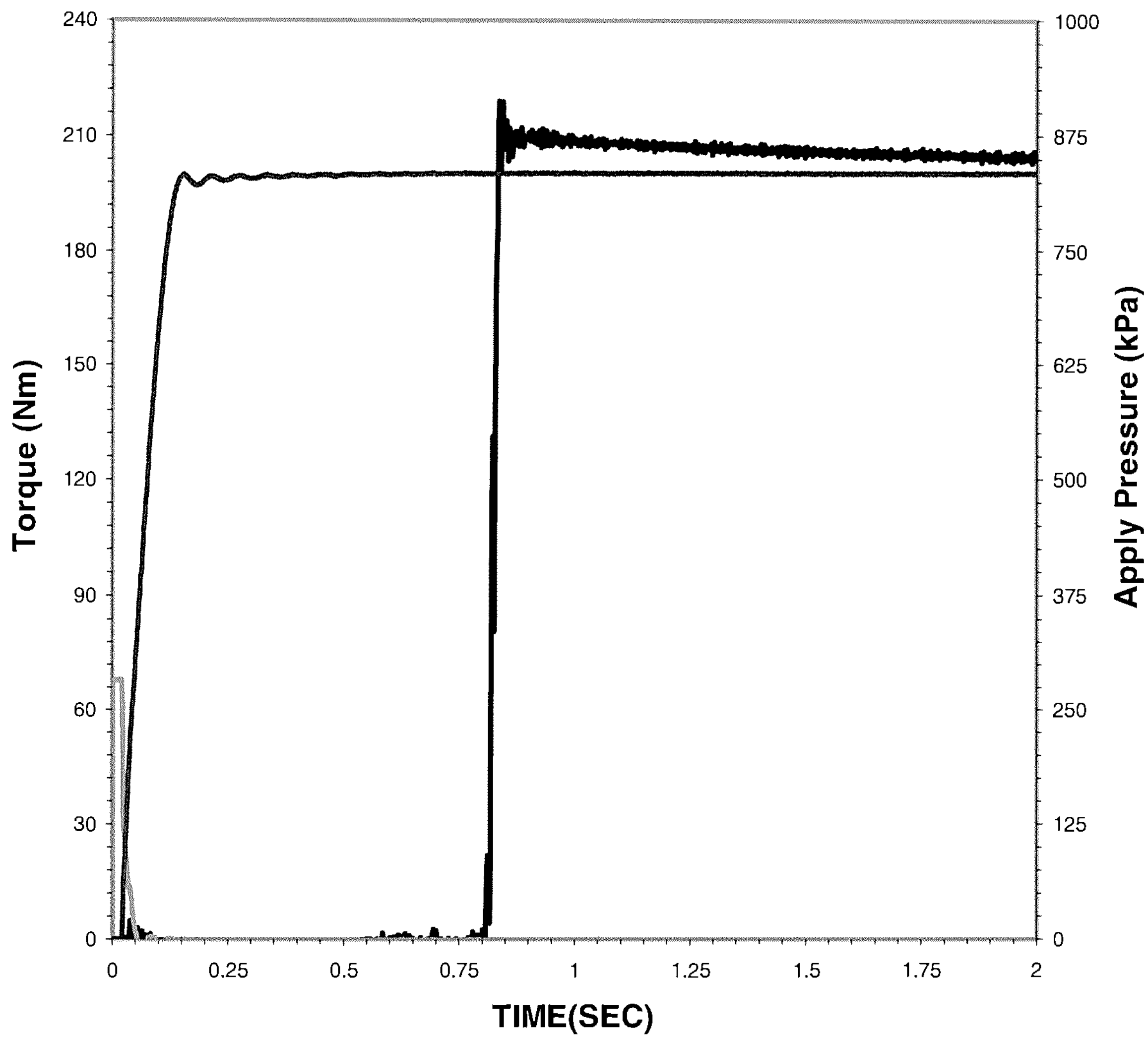
Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 237 Nm
.25 Second: 213 Nm

Coefficient of Friction
Static Peak: 0.164
.25 Second: 0.147

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 1:34:47

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 2000

PHASE B

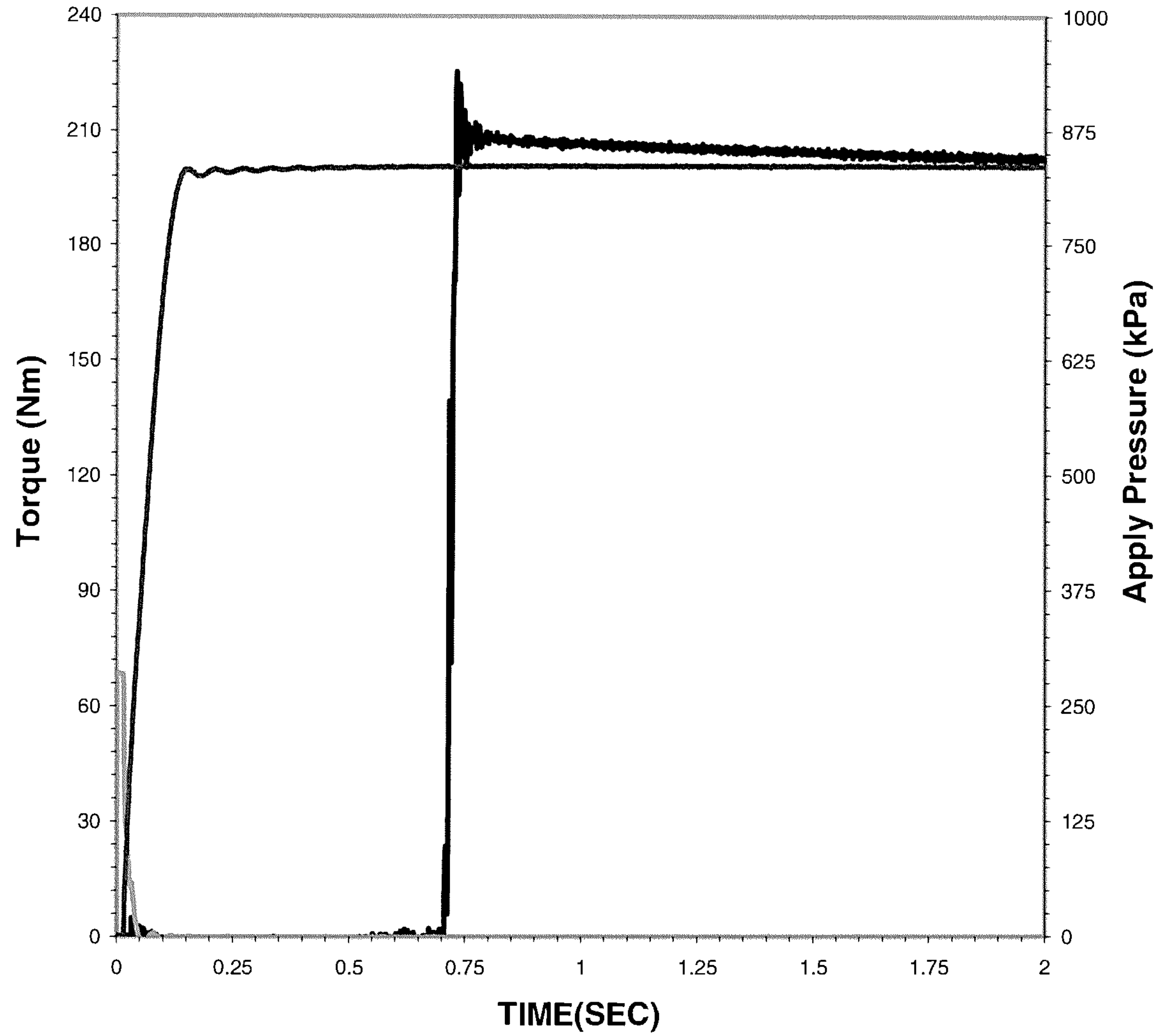
Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 219 Nm
.25 Second: 208 Nm

Coefficient of Friction
Static Peak: 0.152
.25 Second: 0.144

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 3:39:59

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 2500

PHASE B

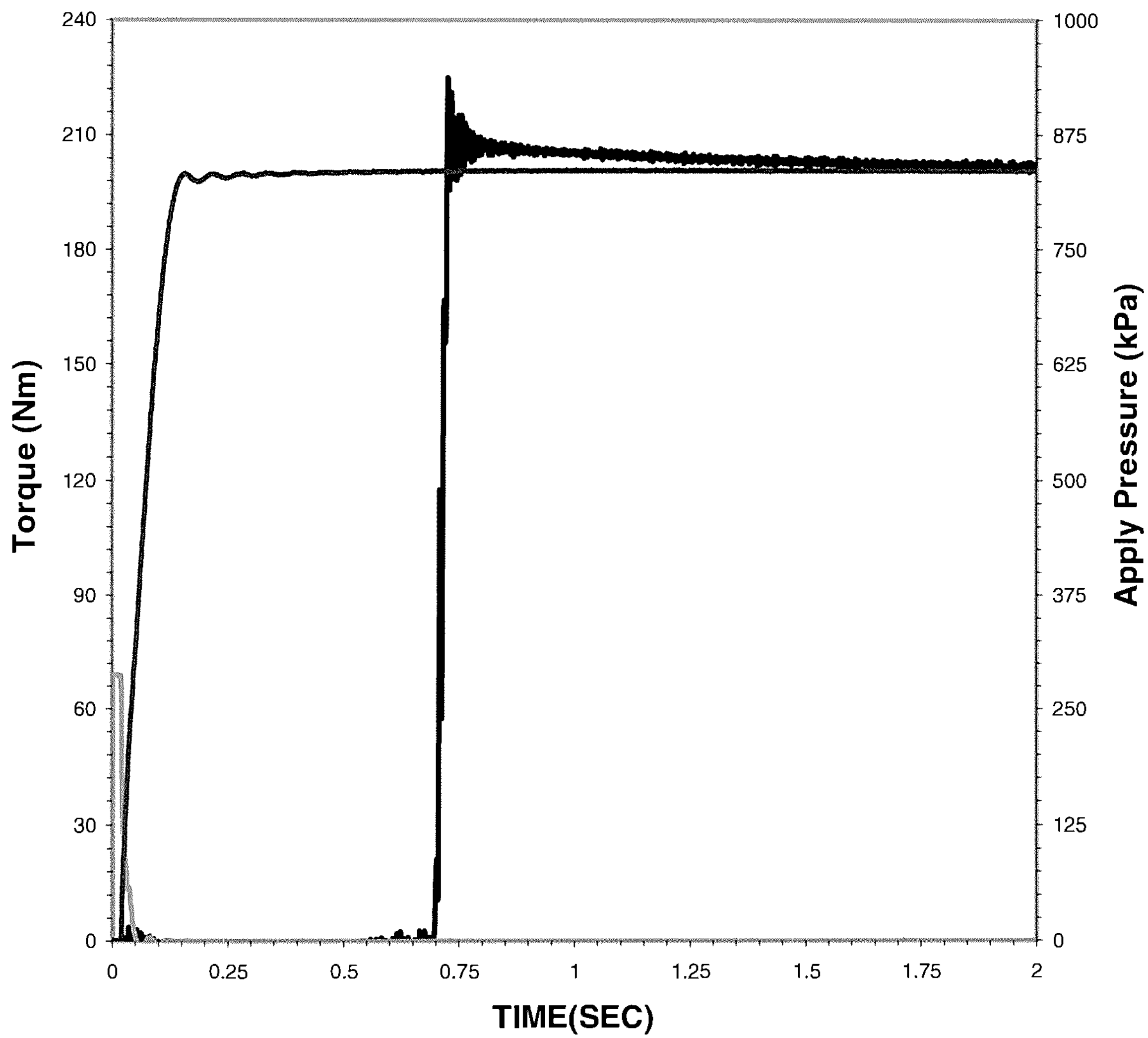
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 226 Nm
.25 Second: 208 Nm

Coefficient of Friction
Static Peak: 0.156
.25 Second: 0.144

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 5:45:11

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 3000

PHASE B

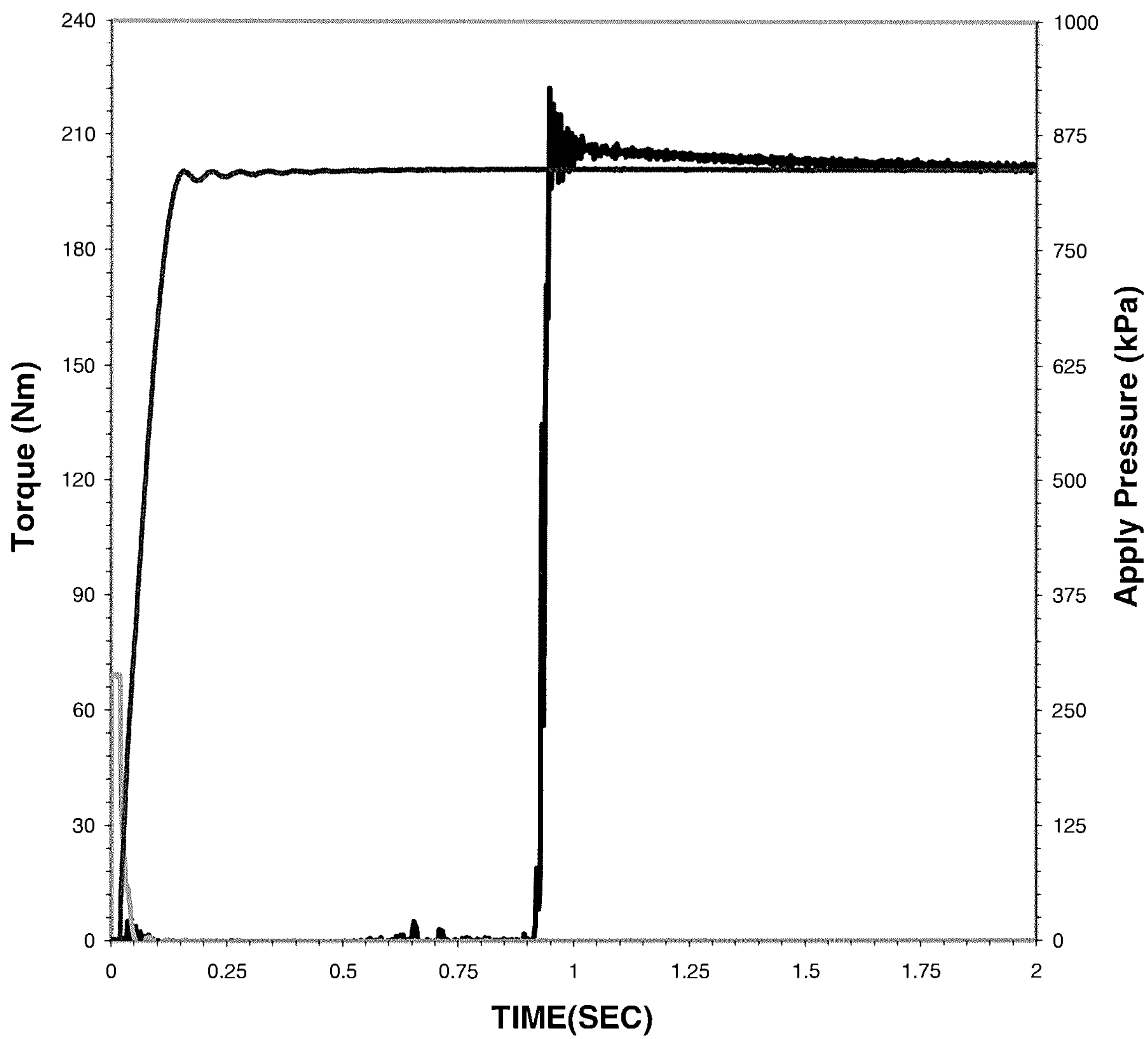
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 226 Nm
.25 Second: 206 Nm

Coefficient of Friction
Static Peak: 0.156
.25 Second: 0.142

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 7:50:23

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 3500

PHASE B

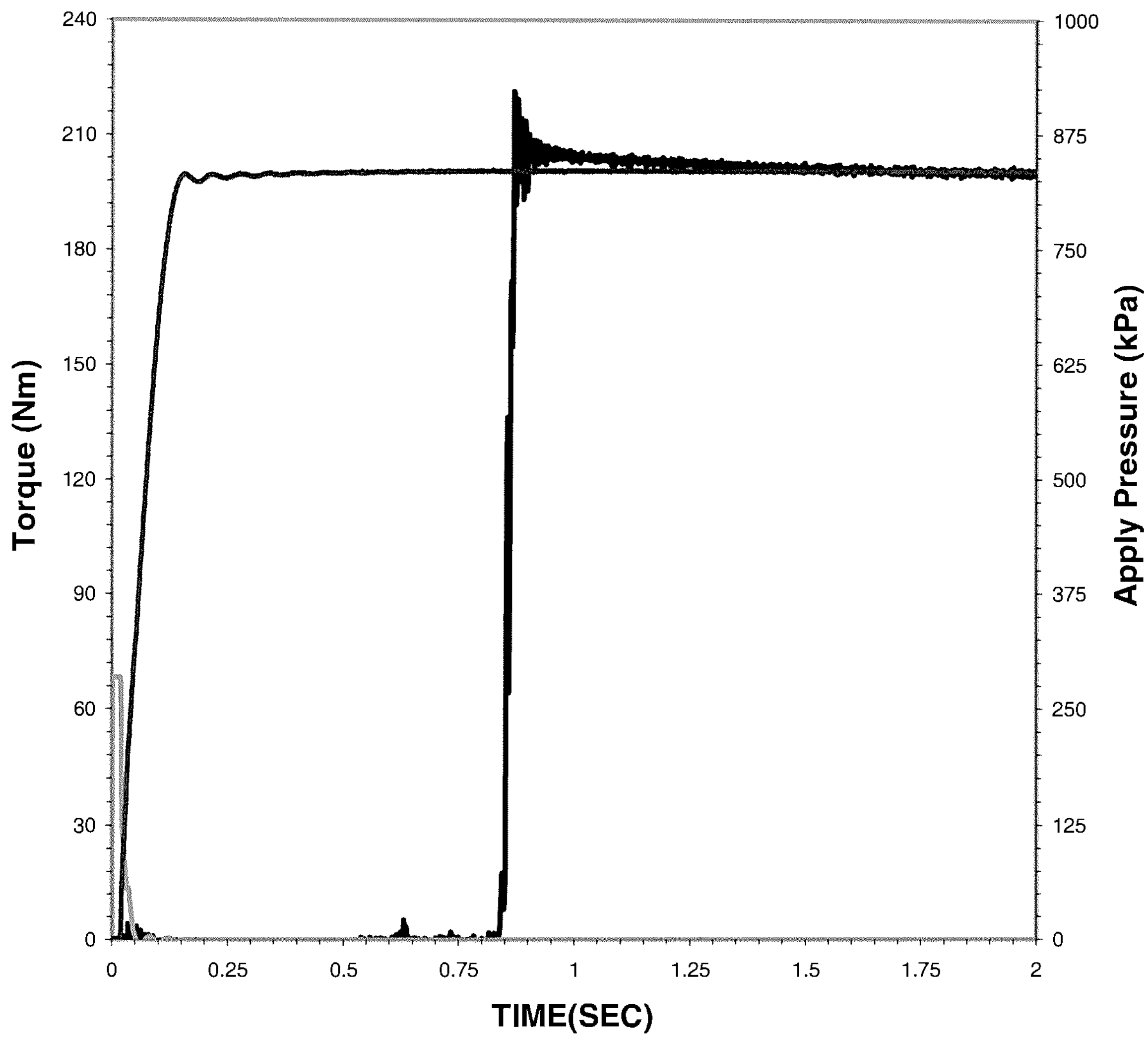
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 223 Nm
.25 Second: 206 Nm

Coefficient of Friction
Static Peak: 0.154
.25 Second: 0.143

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 9:55:35

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 4000

PHASE B

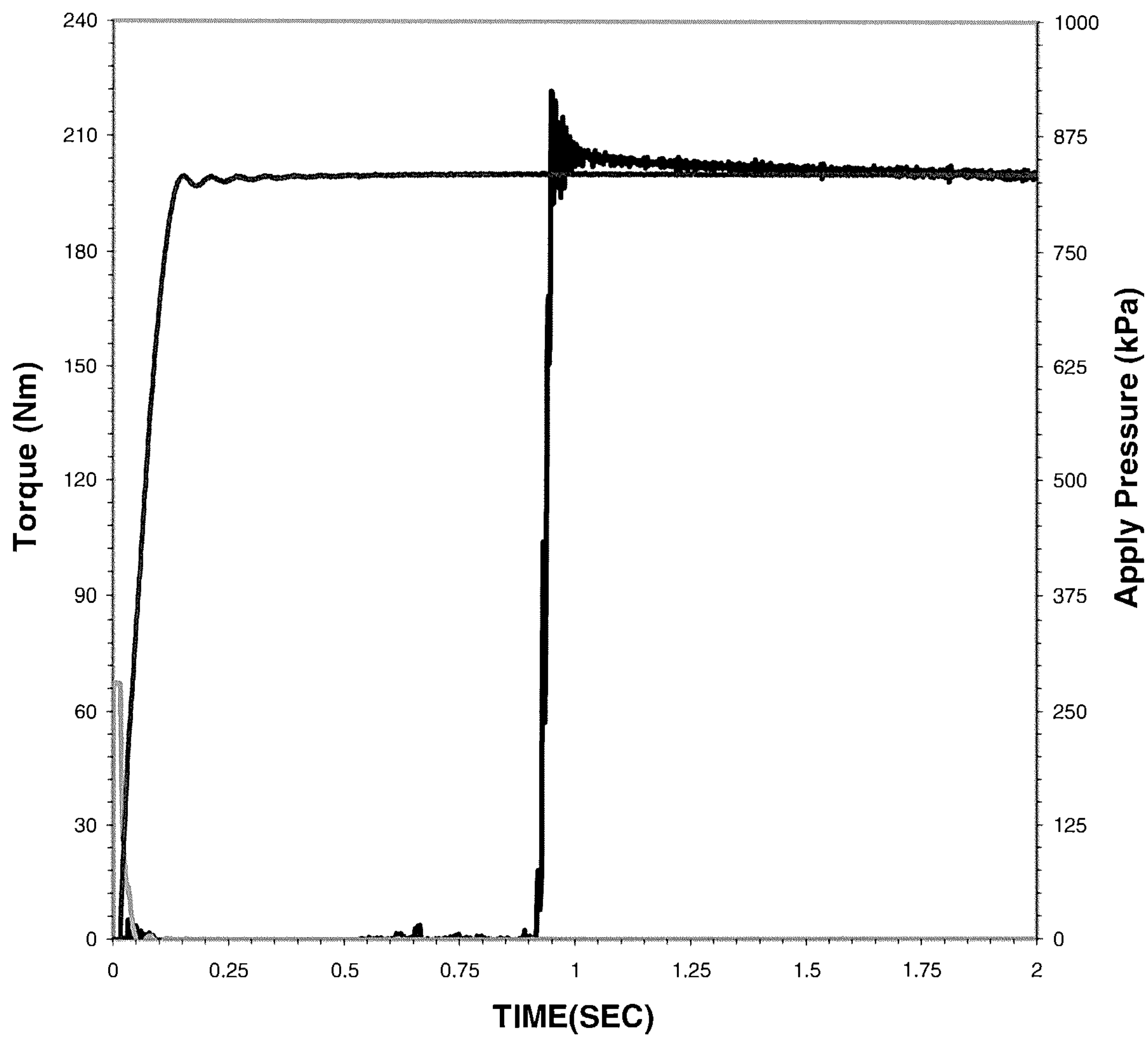
Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 222 Nm
.25 Second: 204 Nm

Coefficient of Friction
Static Peak: 0.153
.25 Second: 0.141

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 12:00:46

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 4500

PHASE B

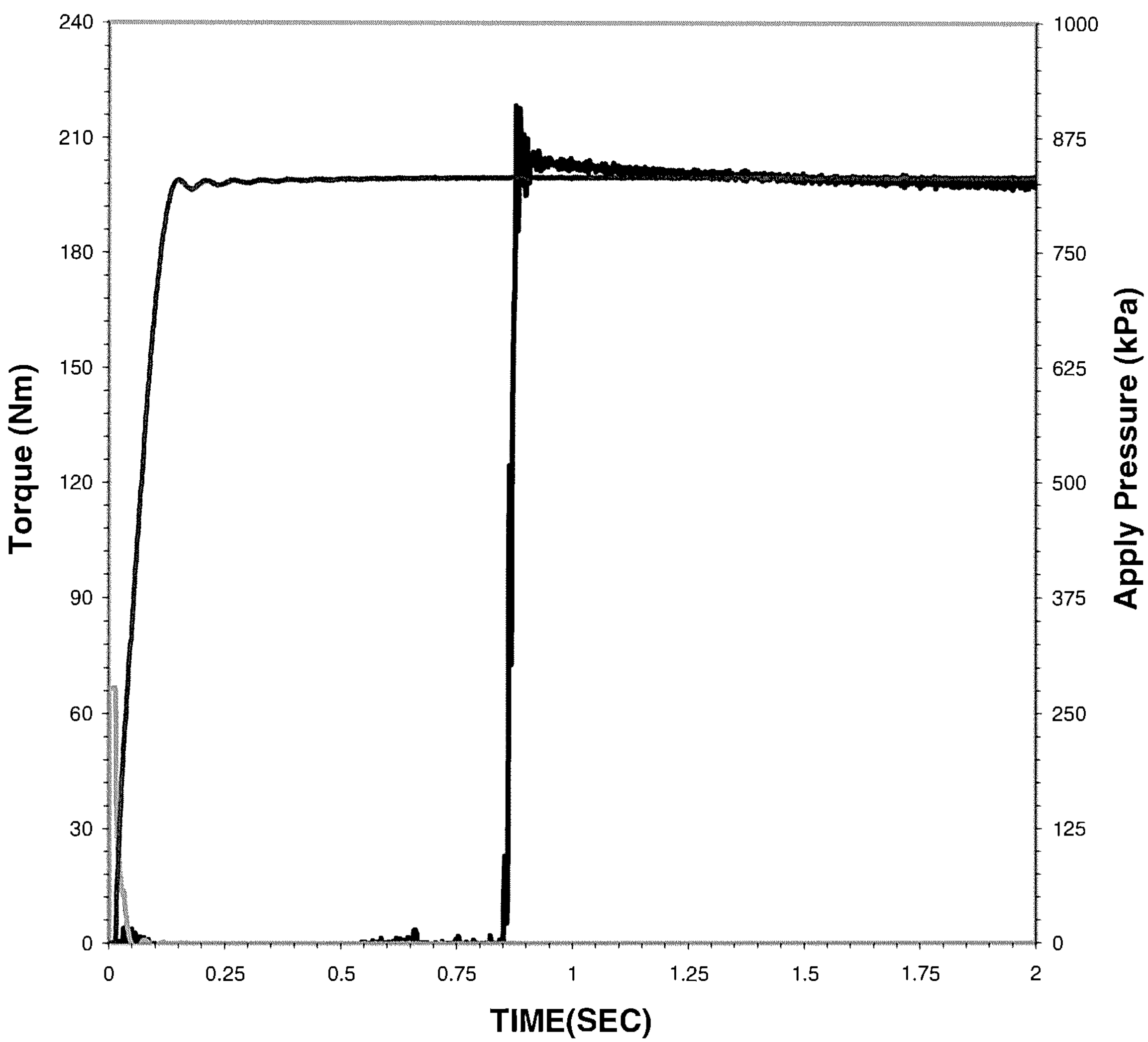
Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 222 Nm
.25 Second: 204 Nm

Coefficient of Friction
Static Peak: 0.154
.25 Second: 0.141

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 14:05:58

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 5000

PHASE B

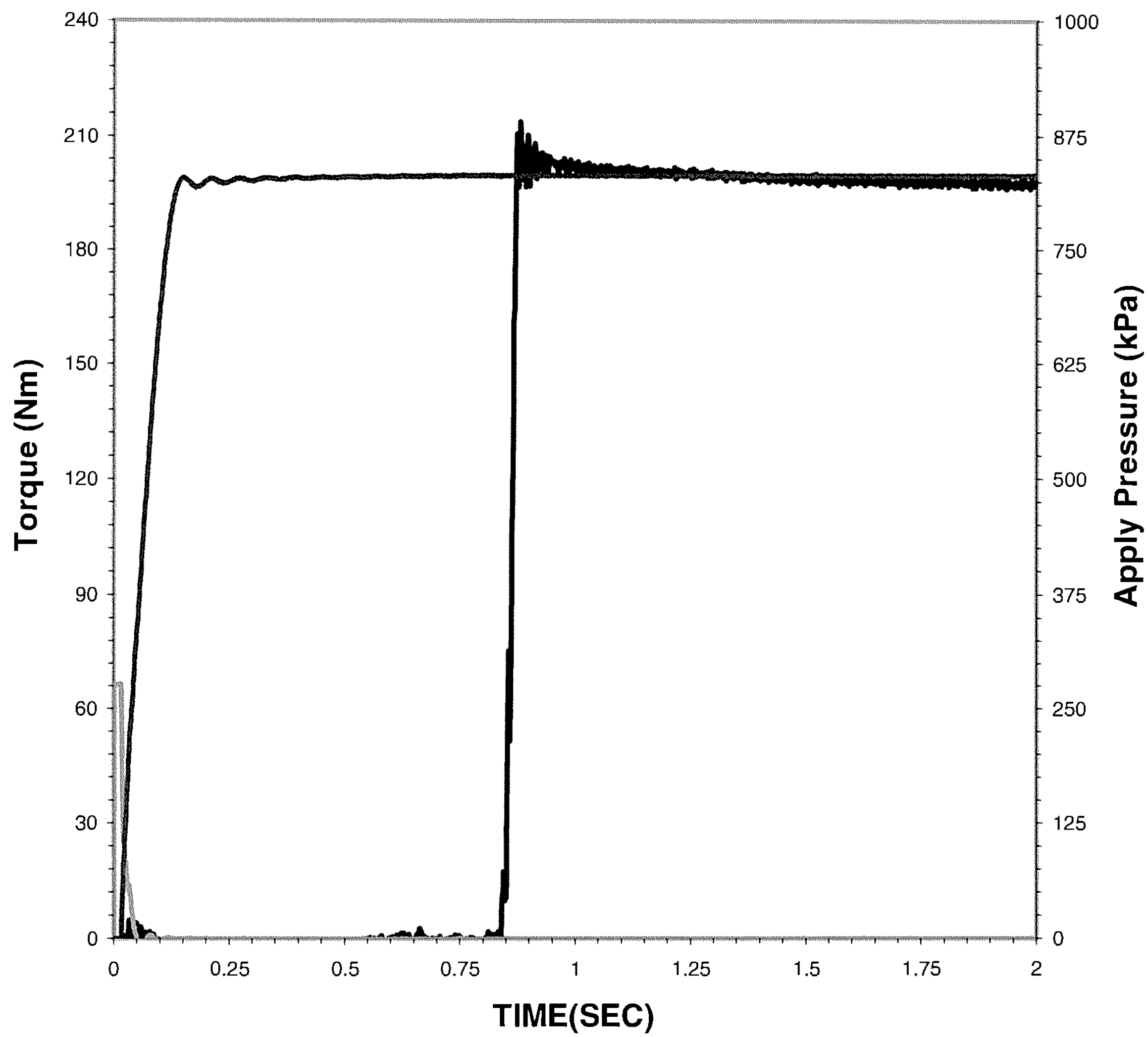
Apply Pressure:
At .25 Second: 830 kPa

Torque
Static Peak: 219 Nm
.25 Second: 201 Nm

Coefficient of Friction
Static Peak: 0.151
.25 Second: 0.139

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 16:11:10

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 5500

PHASE B

Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 214 Nm
.25 Second: 202 Nm

Coefficient of Friction
Static Peak: 0.148
.25 Second: 0.140

APPENDIX – D2 (PART 2)
TYPE C-4 PAPER CLUTCH FRICTION TEST
LO271510

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HEAVY-DUTY TRANSMISSION FLUID
TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted for

ARMY LAB

Oil Code:
LO271510

Test Number:
C2-4-1574

October 17, 2011

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

IX. Paper Clutch Friction Test

Test Laboratory: SWRI
Test Number: C2-4-1574
Friction Plate Batch: LOT 6
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-271510
Sponsor Fluid Code: LO271510
Completion Date: 10/17/11

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0010	0.0004
Clutch Plate	0.1310	0.1174

	Before	After
Pack Clearance	0.8890	1.1176

Reference Tests

Test Number	Test Date	Test Fluid
C2-0-1557	08/12/10	RDL-2746 08-05
C2-0-1568	12/10/10	RDL-2746 08-05
C2-0-1570	01/13/11	RDL-2746 08-05

	New	EOT
Viscosity at 40°C, cSt	45.39	40.01
Viscosity at 100°C, cSt	8.48	7.80
Iron Content, ppm	1	181

D5185	New Fluid (ppm)
Ba	<1
B	18
Ca	896
Mg	1255
P	1055
Si	6
Na	<5
Zn	1272

Name: Matthew Jackson
Title: Manager

Signature:
Date: 10/25/11

ALLISON C- 4 PAPER FRICTION TEST

(Torque in N*m)

Sponsor Fluid Code:	**LO271510**	Test Number:	**C2-4-1574**
Lab Fluid Code:	**LO-271510**	Fric. Plate Batch:	**Lot 6**
Completion Date:	**10/17/2011**	Steel Plate Batch:	**10/9/2008**

TORQUE

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.50	196	356	160	383	371
500	0.47	209	359	150	383	368
1000	0.45	221	349	128	365	359
2500	0.43	238	336	98	352	343
5000	0.42	244	333	89	353	340
7500	0.43	241	325	84	345	334
10000	0.43	241	325	84	341	335

COEFFICIENT OF FRICTION

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.50	0.095	0.173	0.078	0.187	0.181
500	0.47	0.102	0.175	0.073	0.187	0.179
1000	0.45	0.108	0.170	0.062	0.178	0.175
2500	0.43	0.116	0.164	0.048	0.171	0.167
5000	0.42	0.119	0.162	0.043	0.172	0.166
7500	0.43	0.117	0.158	0.041	0.168	0.163
10000	0.43	0.117	0.158	0.041	0.166	0.163

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.500	0.430	-14.00	P
Mid-Point Fric. Coeff. Min.	0.085	N/A	0.095	0.117	23.16	P
Static Friction Coeff.	N/A	N/A	0.173	0.158	-8.67	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.187	0.166	-11.23	
0.25 Second Low Speed Coeff.	N/A	N/A	0.181	0.163	-9.94	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-PAPER FRICTION TEST

(all units in mm)

Candidate Fluid: LO271510 **Test Number : C2-4-1574** **Completion Date : 10/17/2011**

Lab Fluid Code : LO-271510 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 6**

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.0630	1.9430	2.0540	1.9380	0.1200		0.1160
	120	2.0770	1.9460	2.0620	1.9480	0.1310		0.1140
	240	2.0860	1.9570	2.0790	1.9640	0.1290		0.1150
	Average					0.1267	0.1208	0.1150
5	Top	2.0820	1.9690	2.0760	1.9730	0.1130		0.1030
	120	2.0820	1.9620	2.0670	1.9640	0.1200		0.1030
	240	2.0700	1.9440	2.0660	1.9470	0.1260		0.1190
	Average					0.1197	0.1140	0.1083
STEELS SEPARATORS								
1	Top	1.7540	1.7540	1.7540	1.7540	0.0000		0.0000
	120	1.7590	1.7590	1.7580	1.7580	0.0000		0.0000
	240	1.7570	1.7570	1.7570	1.7570	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7550	1.7540	1.7560	1.7560	0.0010		0.0000
	120	1.7540	1.7530	1.7540	1.7530	0.0010		0.0010
	240	1.7550	1.7550	1.7510	1.7500	0.0000		0.0010
	Average					0.0007	0.0007	0.0007
4	Top	1.7520	1.7510	1.7520	1.7520	0.0010		0.0000
	120	1.7510	1.7510	1.7510	1.7500	0.0000		0.0010
	240	1.7510	1.7500	1.7540	1.7530	0.0010		0.0010
	Average					0.0007	0.0007	0.0007
6	Top	1.7510	1.7510	1.7510	1.7500	0.0000		0.0010
	120	1.7520	1.7520	1.7520	1.7520	0.0000		0.0000
	240	1.7510	1.7500	1.7500	1.7500	0.0010		0.0000
	Average					0.0003	0.0003	0.0003

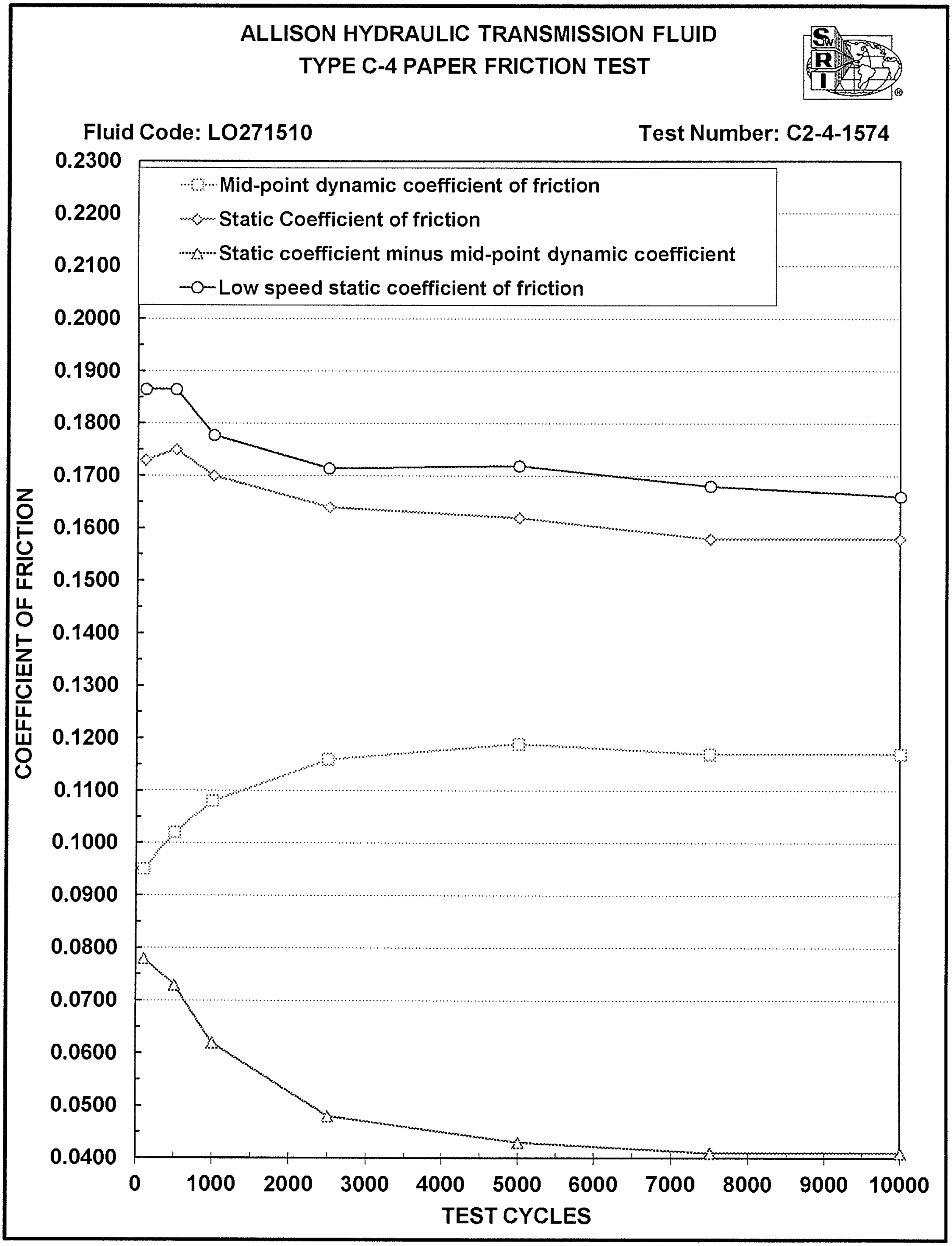
PLATE CONDITION AT E.O.T.: (Anything Unusual) PLATES IN GOOD CONDITION WITH VERY LIGHT DISCOLORATION ON INNER STEEL PLATES. MICROMETER #0221190

Test Date and Operator's Name: 9/28/2011 MARK HOLMES

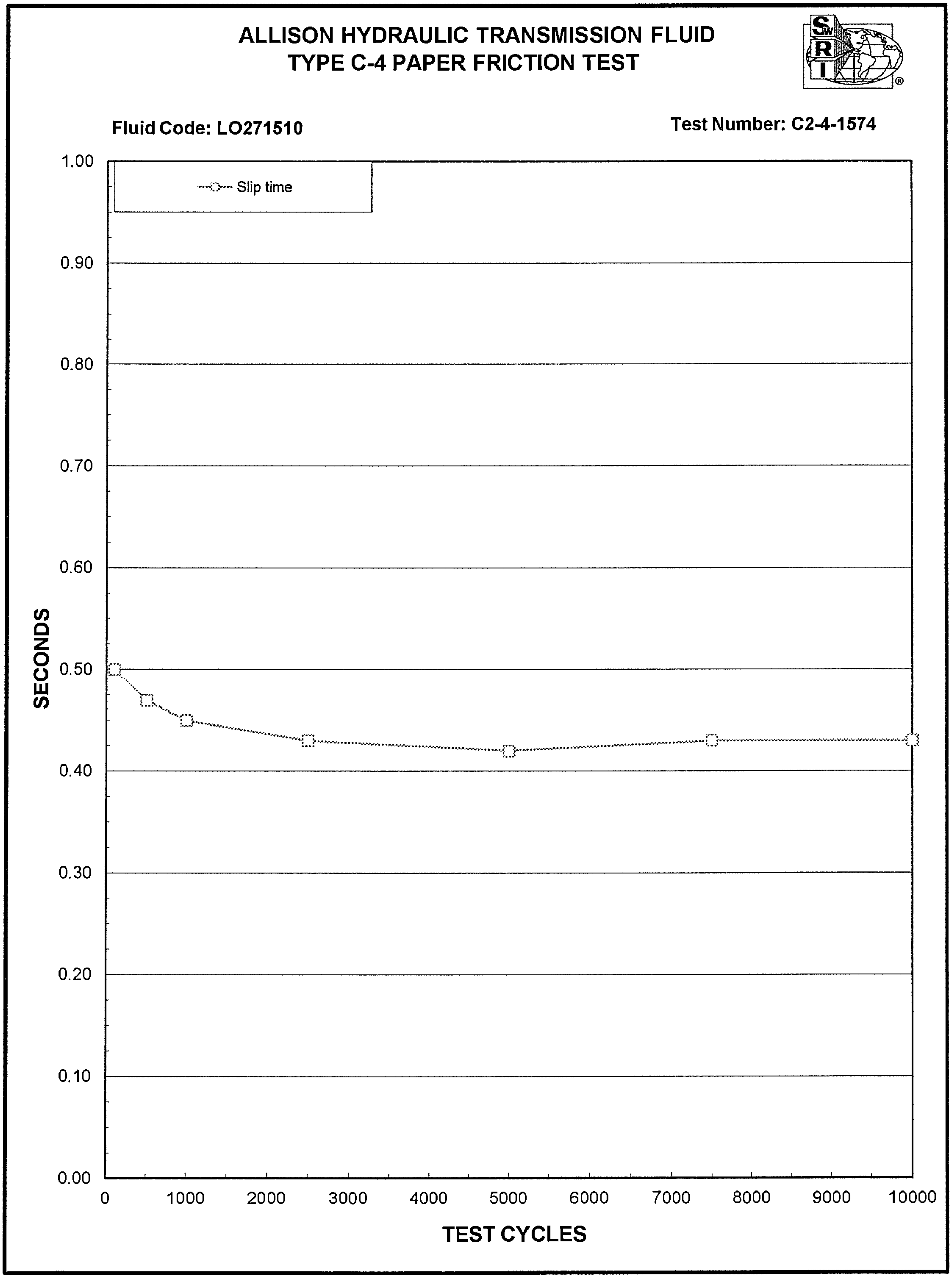
Reviewed By (Signature and Date) 10/24/11

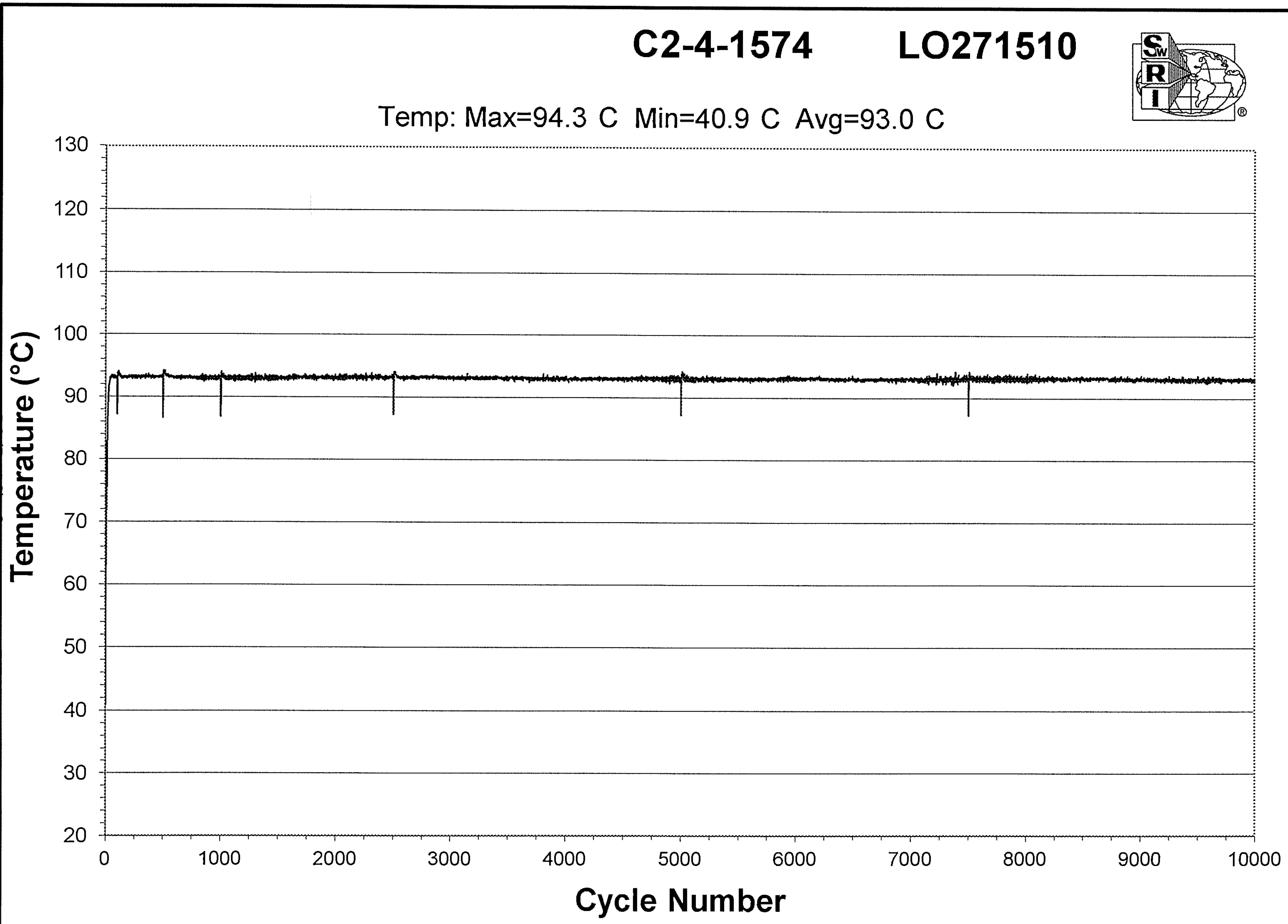
Pack ID#: 4659

C4 Paper Version 1.3 April 26, 2001



ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO271510
Test Number: C2-4-1574
Mid-point dynamic coefficient of friction
Static Coefficient of friction
Static coefficient minus mid-point dynamic coefficient
Low speed static coefficient of friction
COEFFICIENT OF FRICTION
0.2300
0.2200
0.2100
0.2000
0.1900
0.1800
0.1700
0.1600
0.1500
0.1400
0.1300
0.1200
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
TEST CYCLES

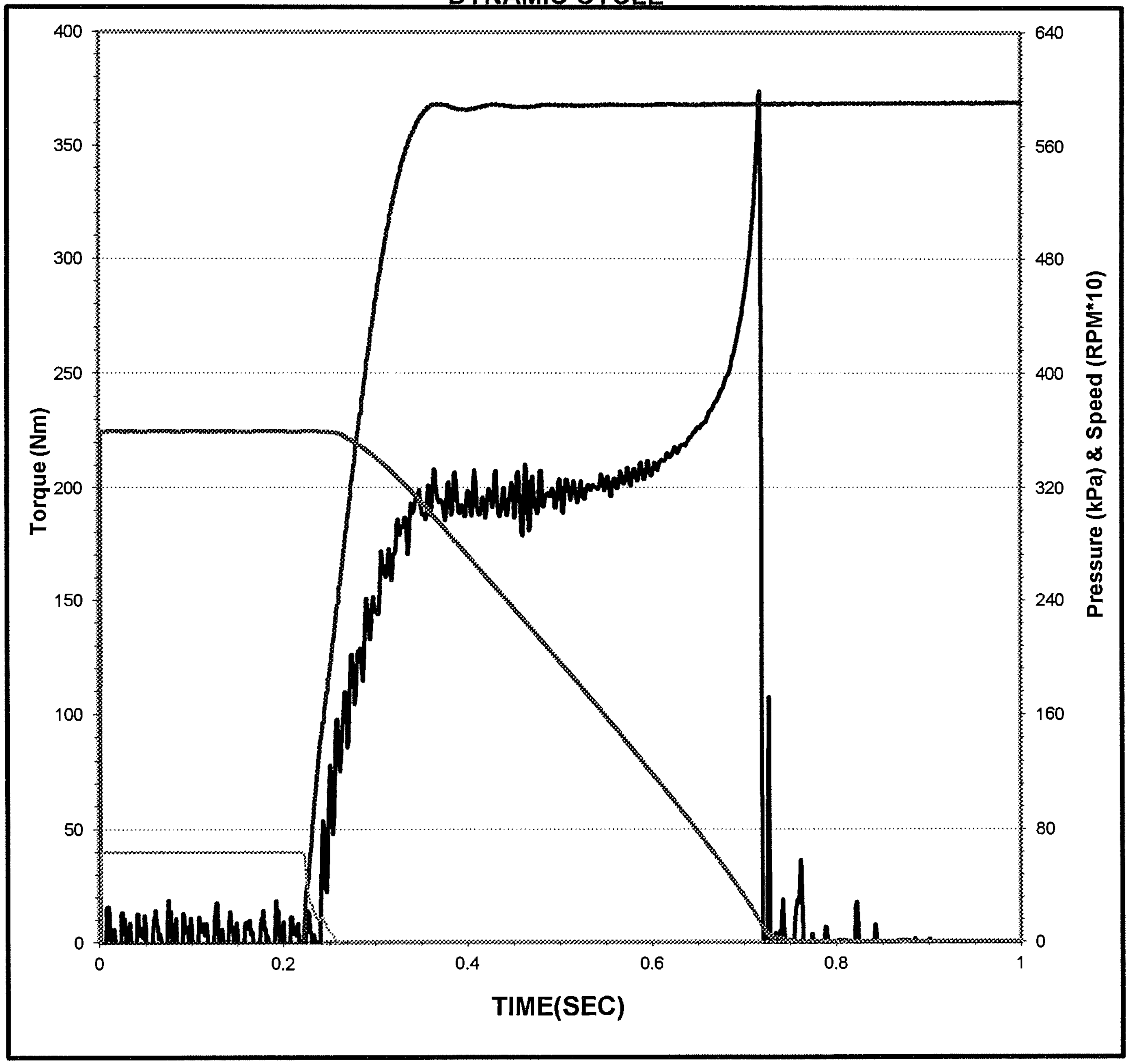

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO271510
Test Number: C2-4-1574
Slip time
SECONDS
TEST CYCLES
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000


C2-4-1574
LO271510
Temp: Max=94.3 C Min=40.9 C Avg=93.0 C
Temperature (°C)
130
120
110
100
90
80
70
60
50
40
30
20
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cycle Number

DYNAMIC TRACES

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	9:29:03
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	10
Temperature:	75.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.498 Sec

Torque

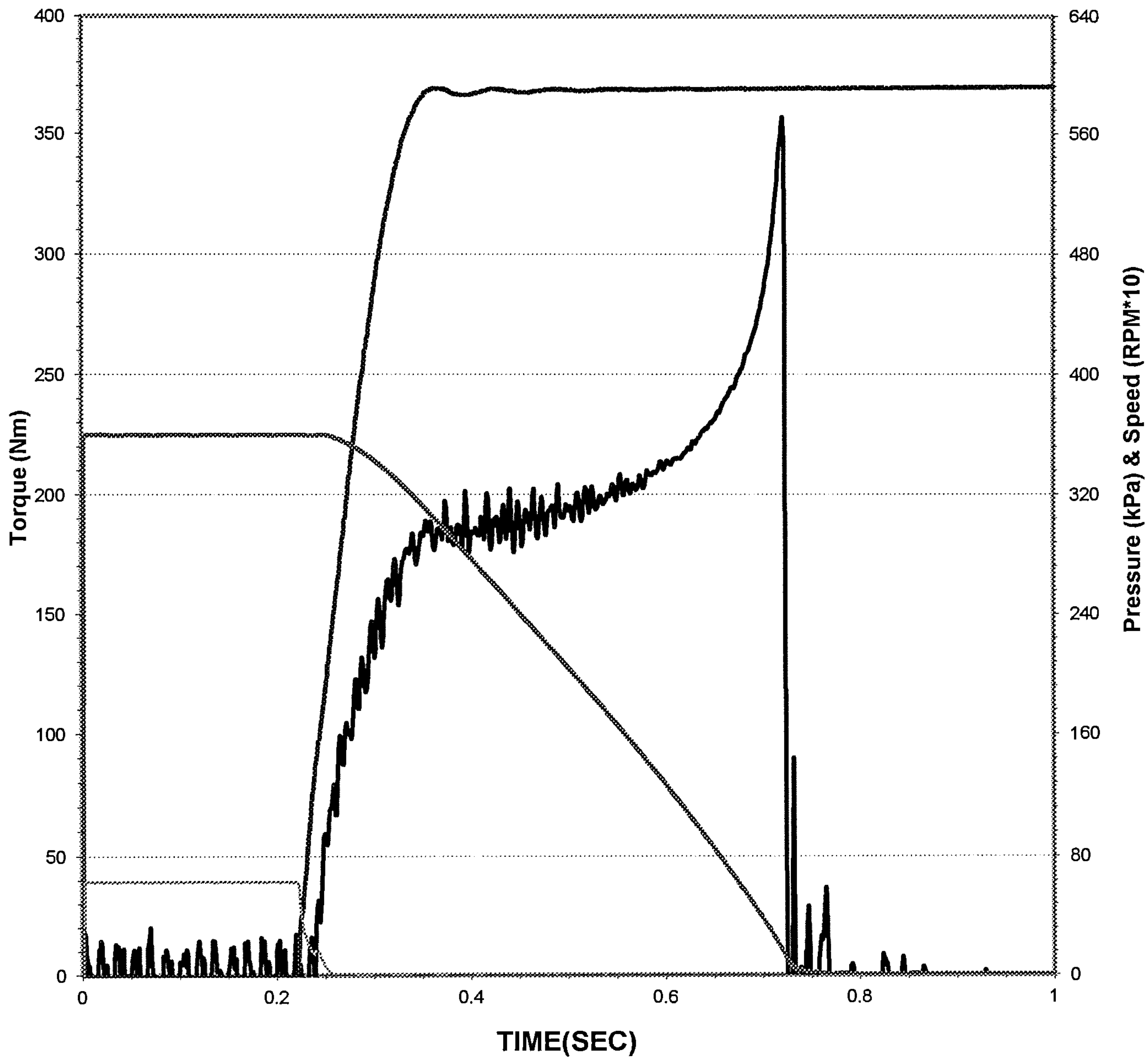
0.2 Sec Dyn:	199 N*m
Midpoint Dyn:	199 N*m
LwSpd Dynamic:	377 N*m

Coefficient of Friction

.2 Sec Dyn:	0.097
Midpoint Dyn:	0.097
LwSpd Dynamic:	0.184

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	9:51:34
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	99
Temperature:	93.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.502 Sec

Torque

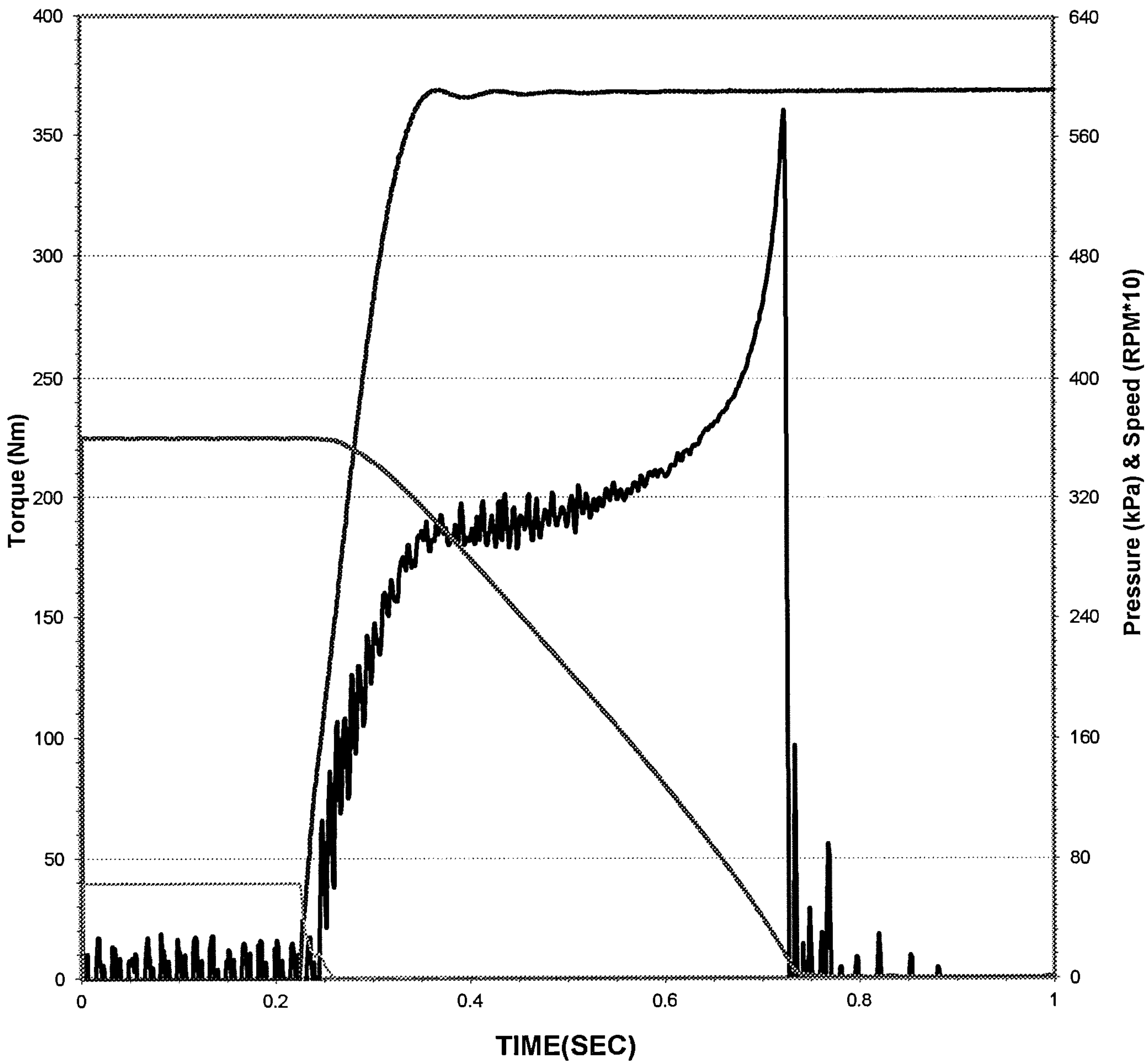
0.2 Sec Dyn:	191 N*m
Midpoint Dyn:	194 N*m
LwSpd Dynamic:	353 N*m

Coefficient of Friction

.2 Sec Dyn:	0.093
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.172

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	9:51:49
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	100
Temperature:	93.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.502 Sec

Torque

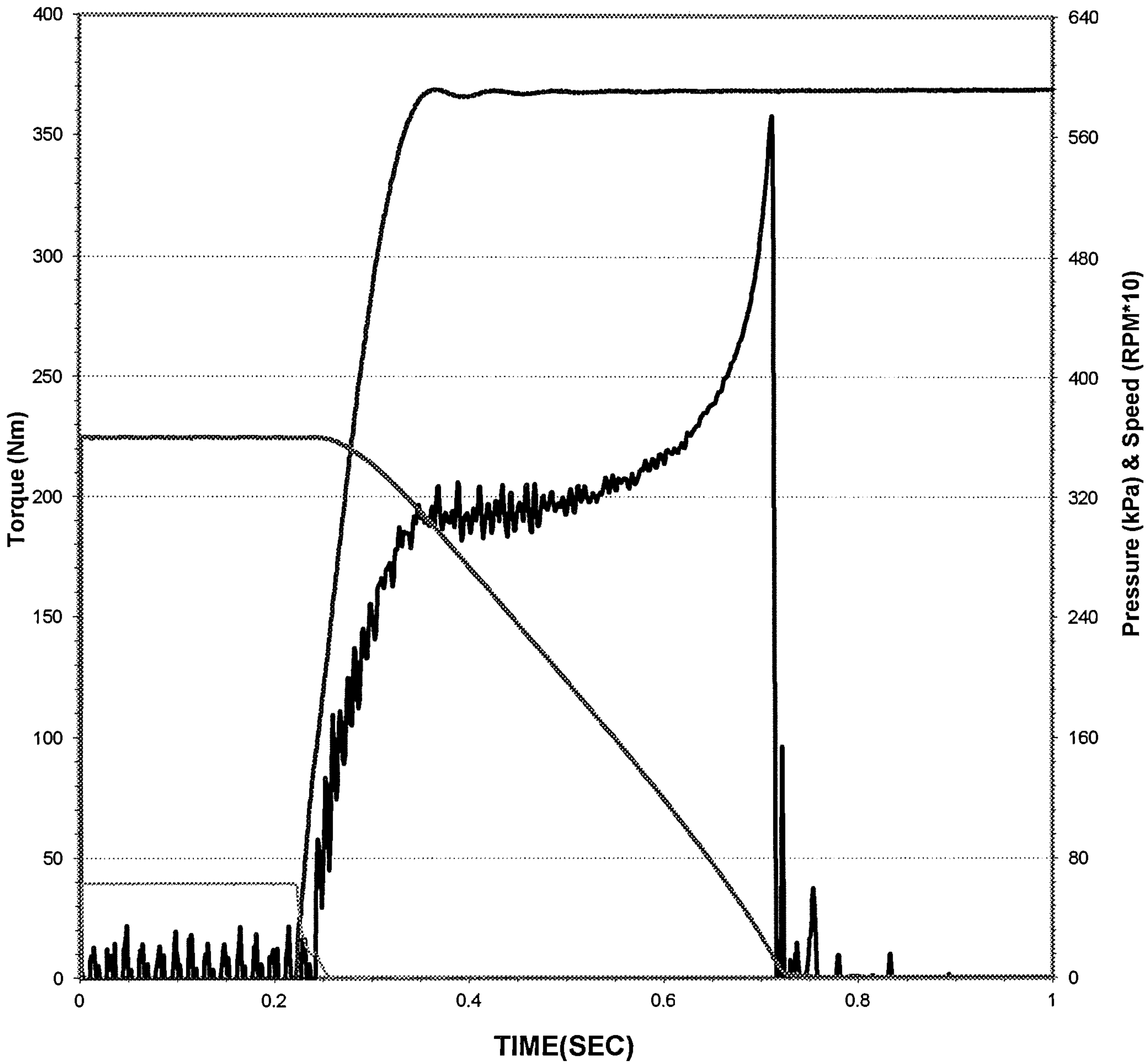
0.2 Sec Dyn:	190 N*m
Midpoint Dyn:	195 N*m
LwSpd Dynamic:	360 N*m

Coefficient of Friction

.2 Sec Dyn:	0.093
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.175

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	9:52:20
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	101
Temperature:	87.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.493 Sec

Torque

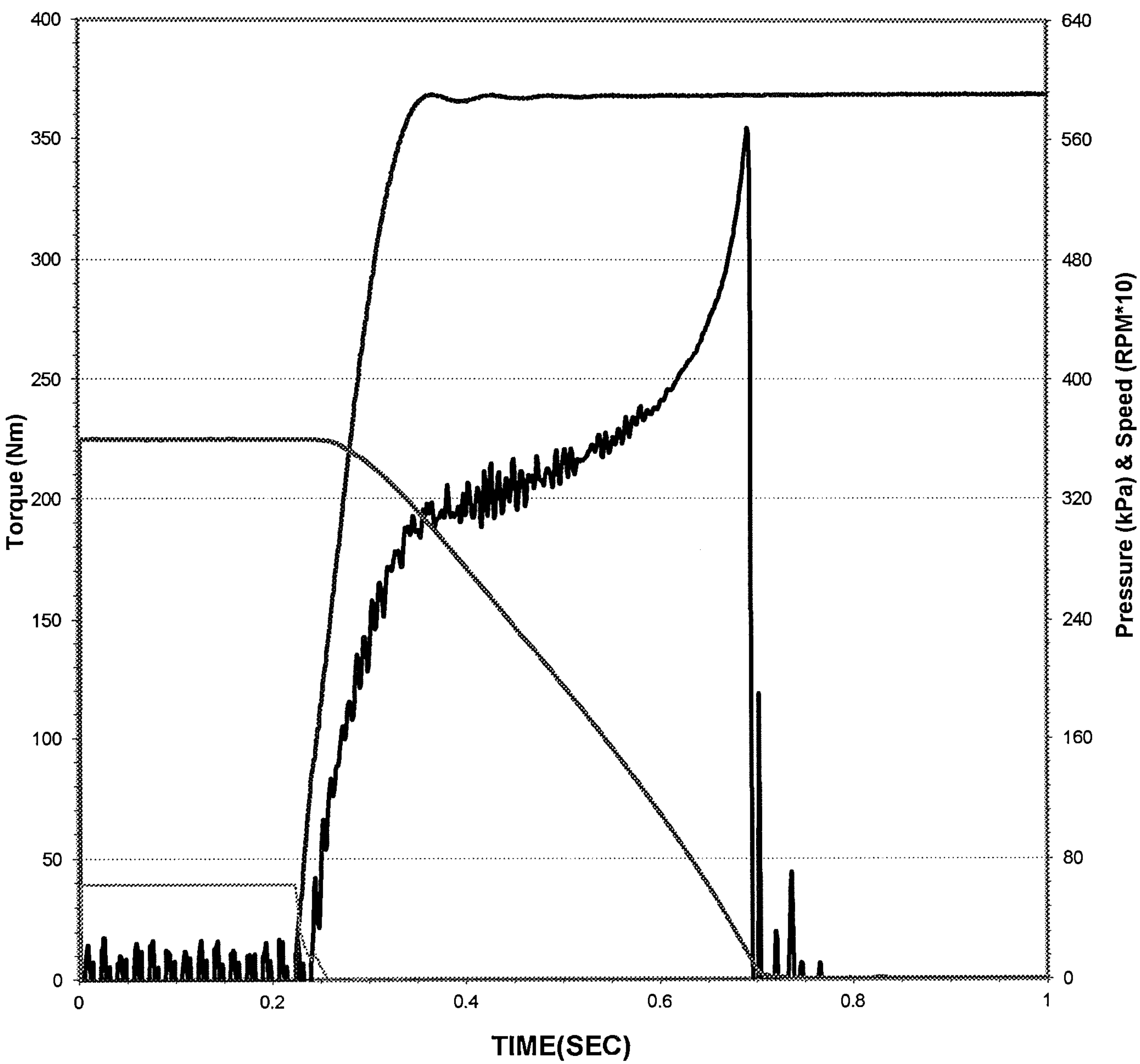
0.2 Sec Dyn:	195 N*m
Midpoint Dyn:	198 N*m
LwSpd Dynamic:	354 N*m

Coefficient of Friction

.2 Sec Dyn:	0.095
Midpoint Dyn:	0.097
LwSpd Dynamic:	0.173

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	11:31:50
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	499
Temperature:	93.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.472 Sec

Torque

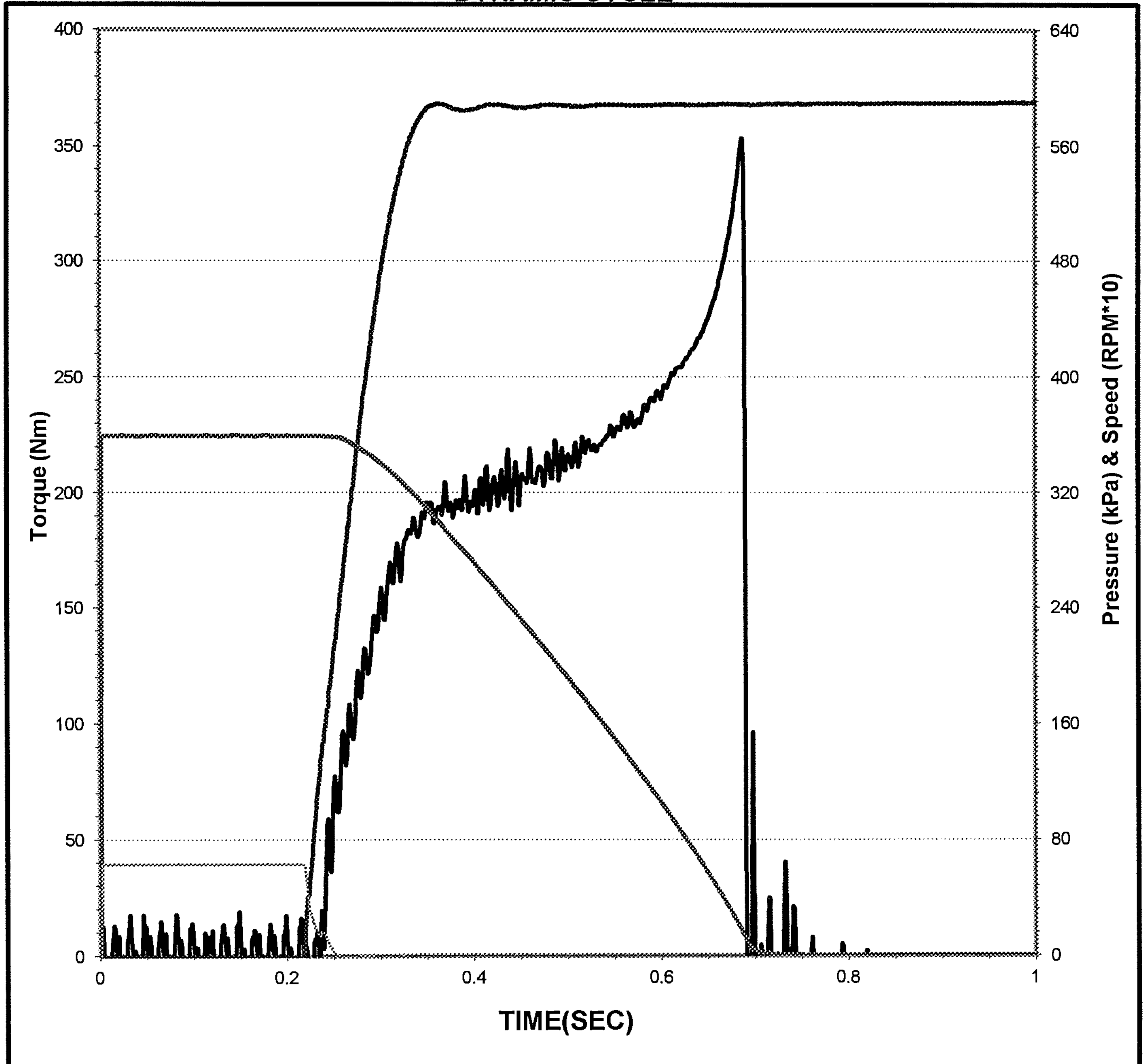
0.2 Sec Dyn:	205 N*m
Midpoint Dyn:	210 N*m
LwSpd Dynamic:	357 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.174

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	11:32:05
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	500
Temperature:	93.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.471 Sec

Torque

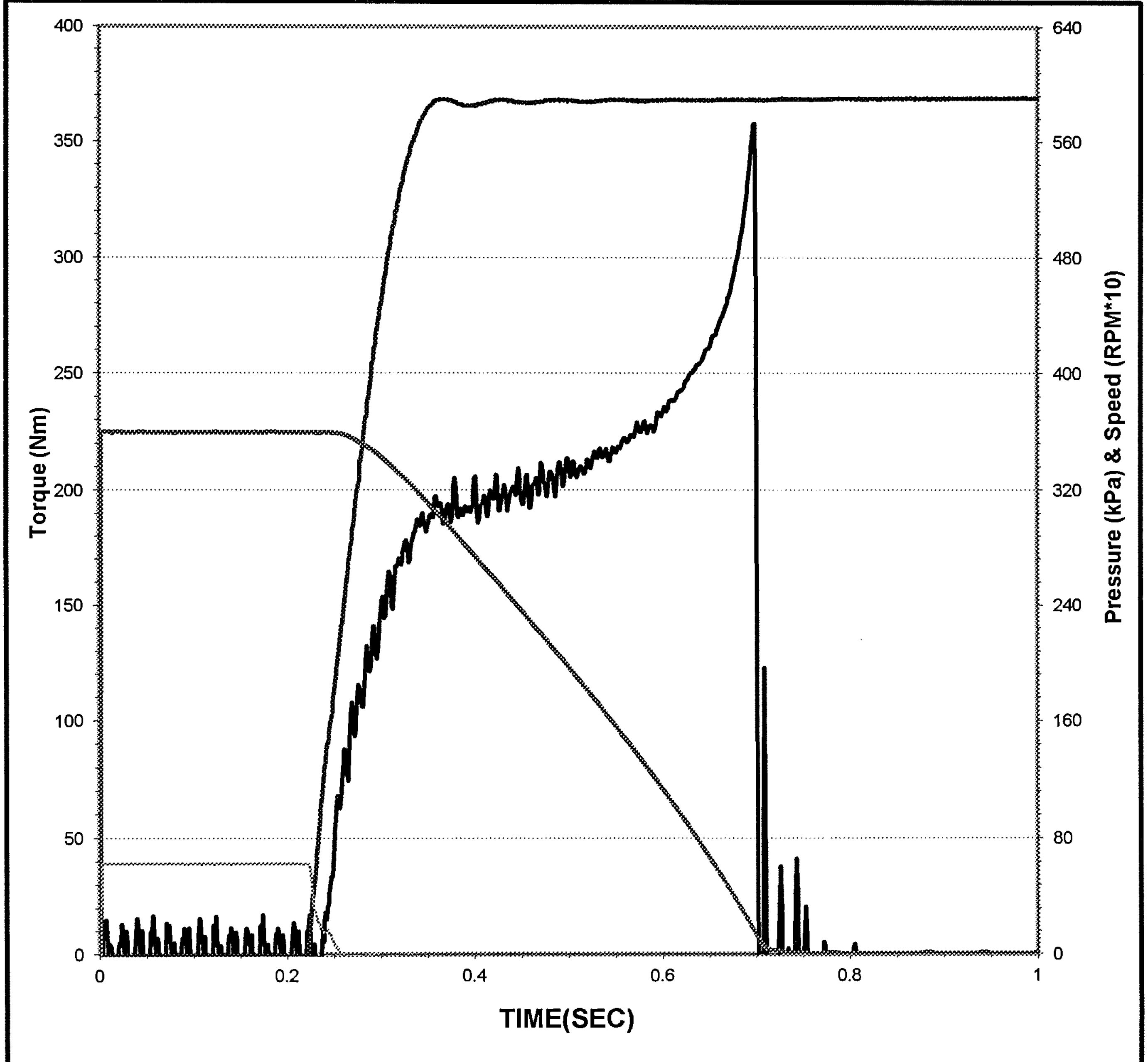
0.2 Sec Dyn:	205 N*m
Midpoint Dyn:	210 N*m
LwSpd Dynamic:	357 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.174

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	11:32:36
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	501
Temperature:	86.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.477 Sec

Torque

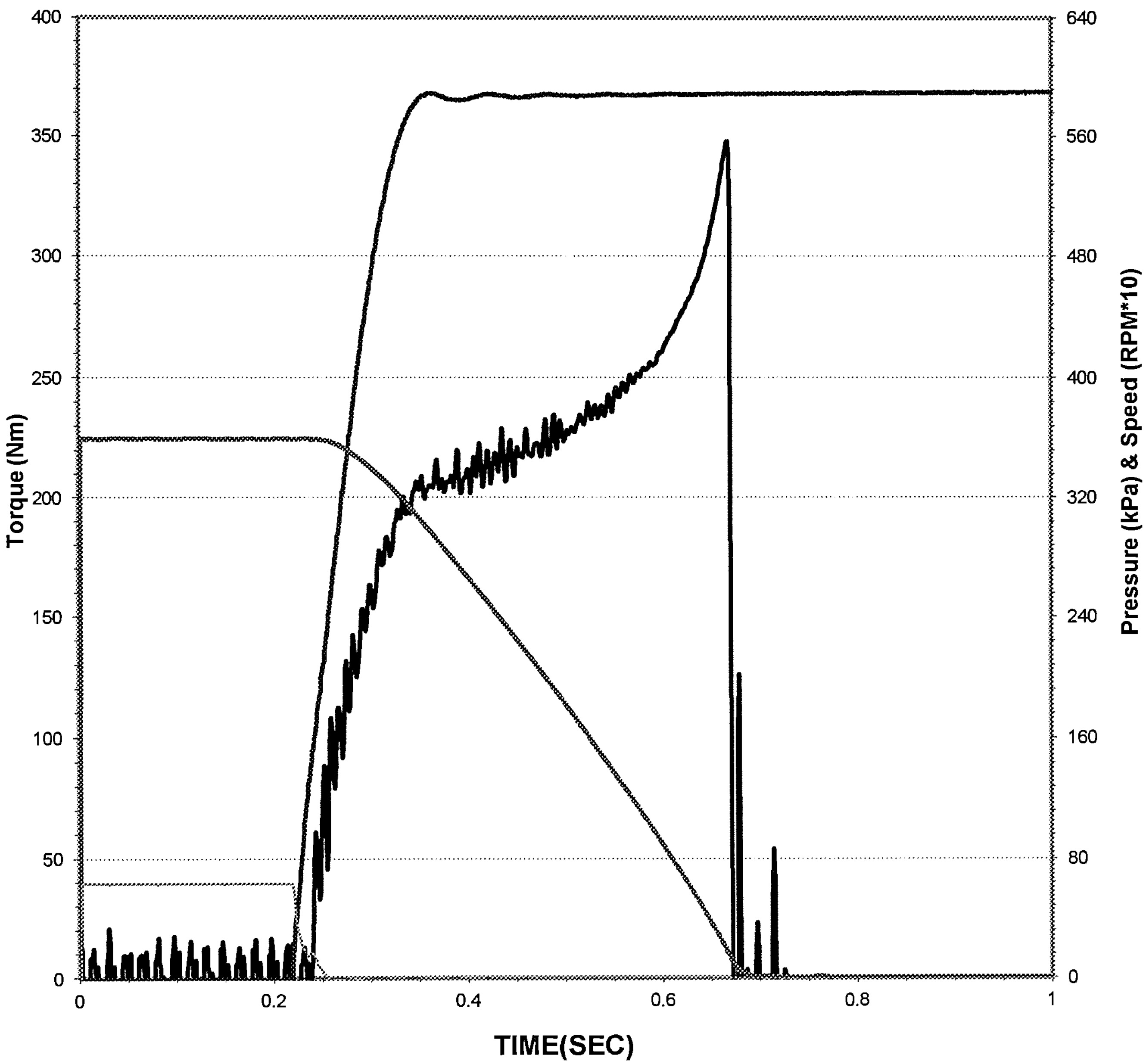
0.2 Sec Dyn:	202 N*m
Midpoint Dyn:	206 N*m
LwSpd Dynamic:	362 N*m

Coefficient of Friction

.2 Sec Dyn:	0.098
Midpoint Dyn:	0.100
LwSpd Dynamic:	0.176

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	13:37:06
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	999
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.452 Sec

Torque

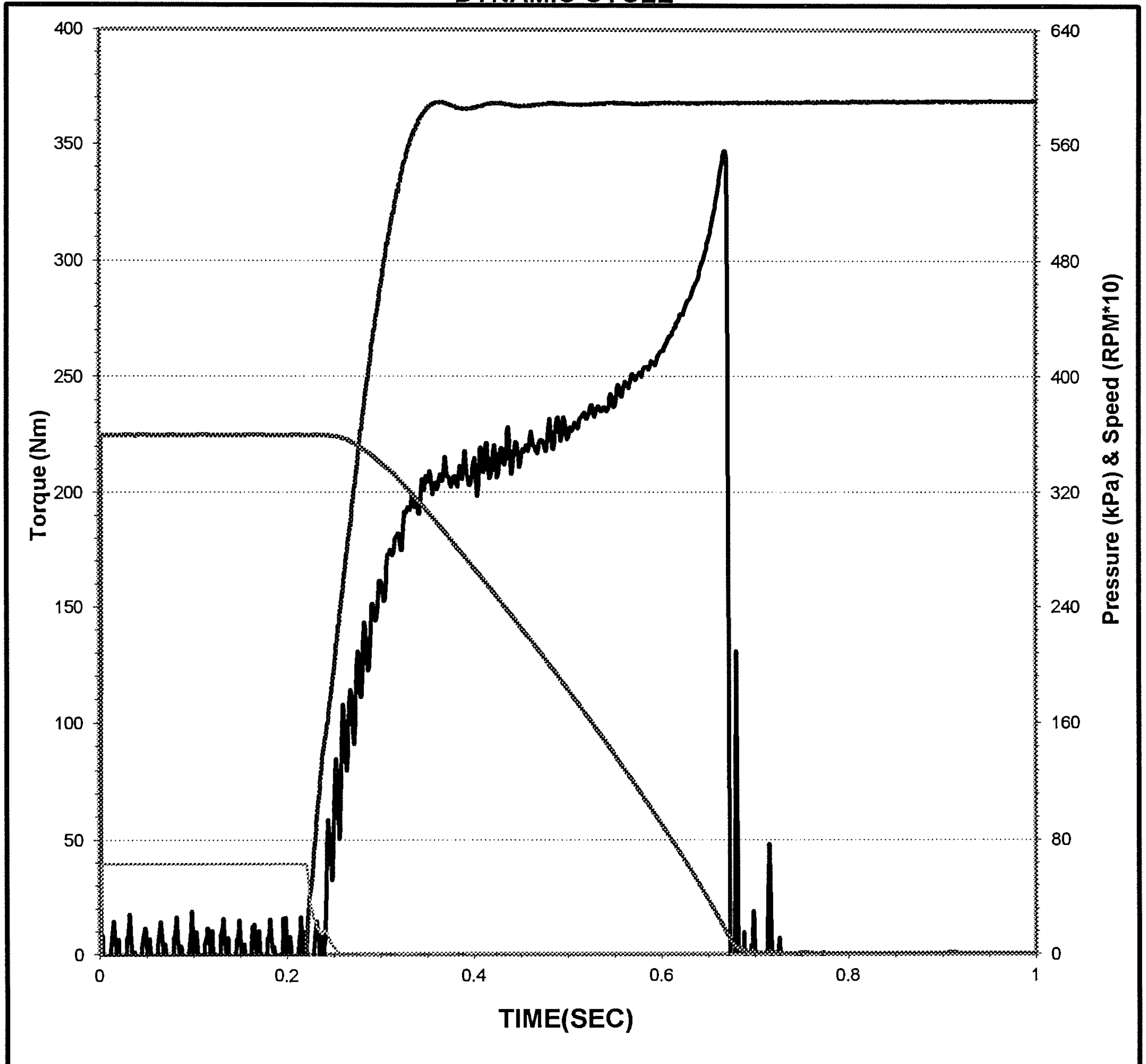
0.2 Sec Dyn:	217 N*m
Midpoint Dyn:	222 N*m
LwSpd Dynamic:	348 N*m

Coefficient of Friction

.2 Sec Dyn:	0.106
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.169

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	13:37:21
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	1000
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.451 Sec

Torque

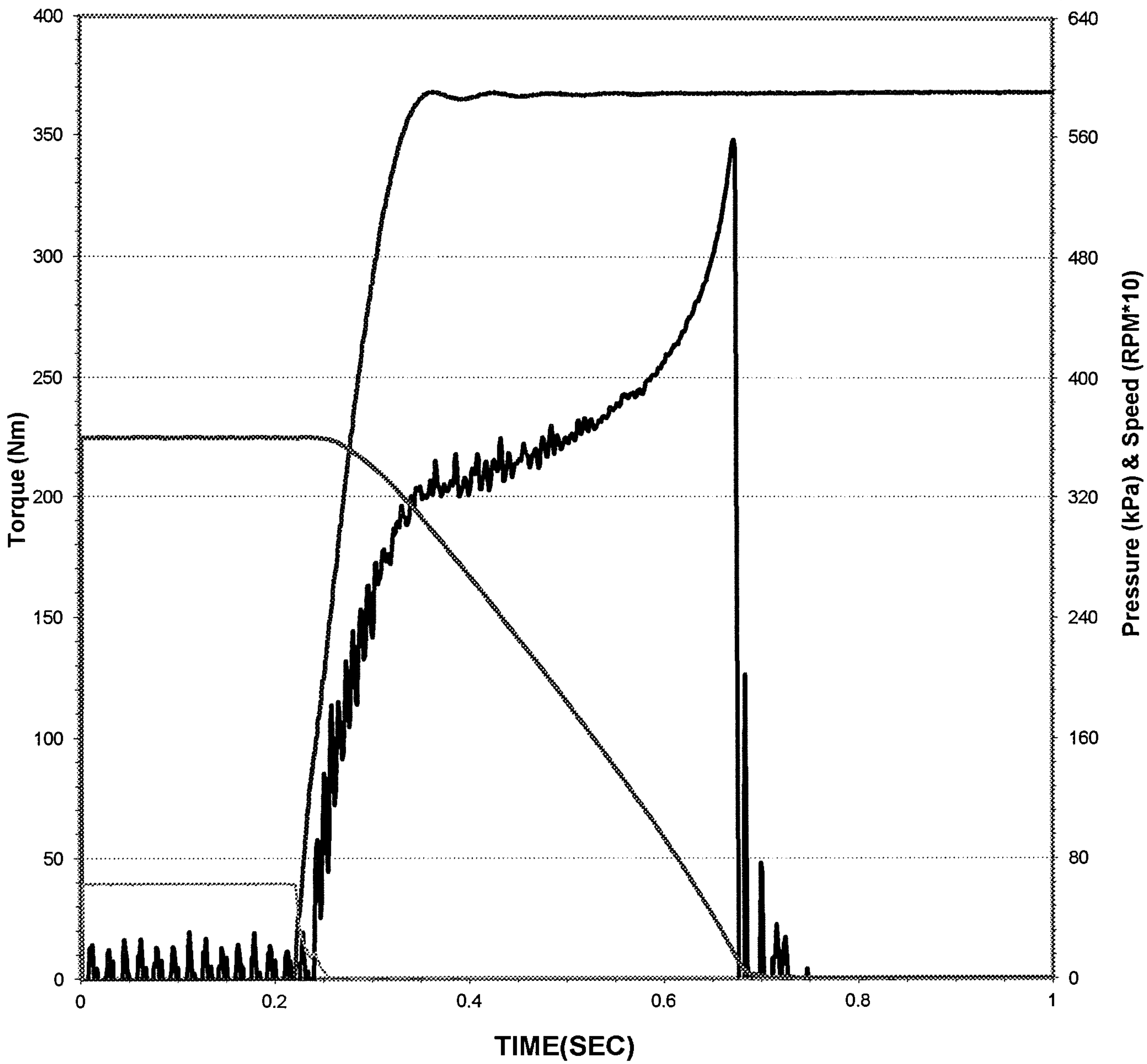
0.2 Sec Dyn:	217 N*m
Midpoint Dyn:	222 N*m
LwSpd Dynamic:	349 N*m

Coefficient of Friction

.2 Sec Dyn:	0.106
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.170

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	13:37:53
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	1001
Temperature:	86.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.455 Sec

Torque

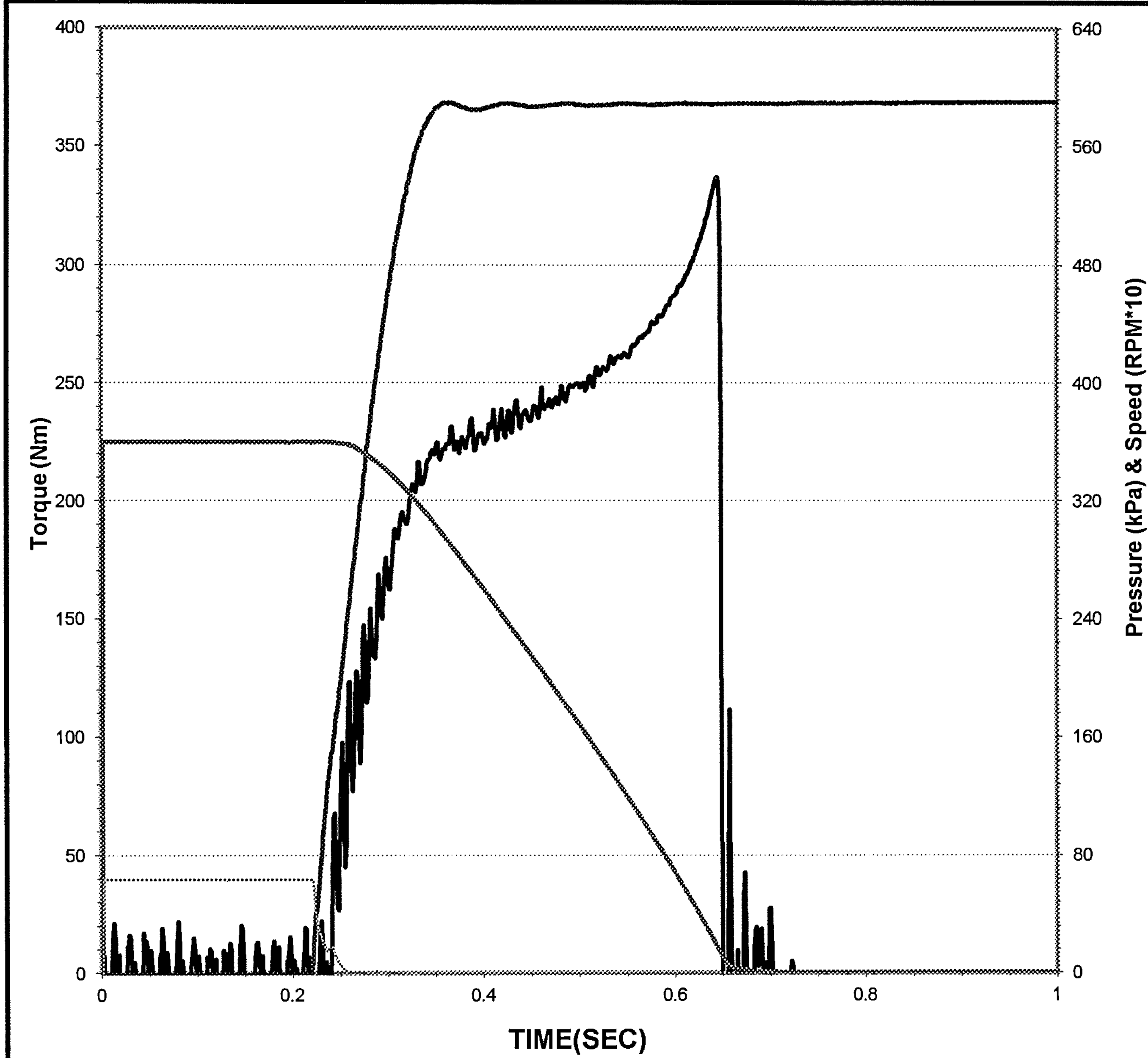
0.2 Sec Dyn:	215 N*m
Midpoint Dyn:	219 N*m
LwSpd Dynamic:	350 N*m

Coefficient of Friction

.2 Sec Dyn:	0.105
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.171

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 10/15/2011

Time of Test: 19:52:23

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 2499

Temperature: 93.3 °C (93.3 ± 3.0 °C)

Apply Pressure: 589 kPa (586 ± 7 KPa)

Apply Rate: 0.13 Sec (0.15 ± 0.02 Sec)

Energy: 18.6 KJ (18.7 ± 0.40 KJ)

Engage Time: 0.428 Sec

Torque

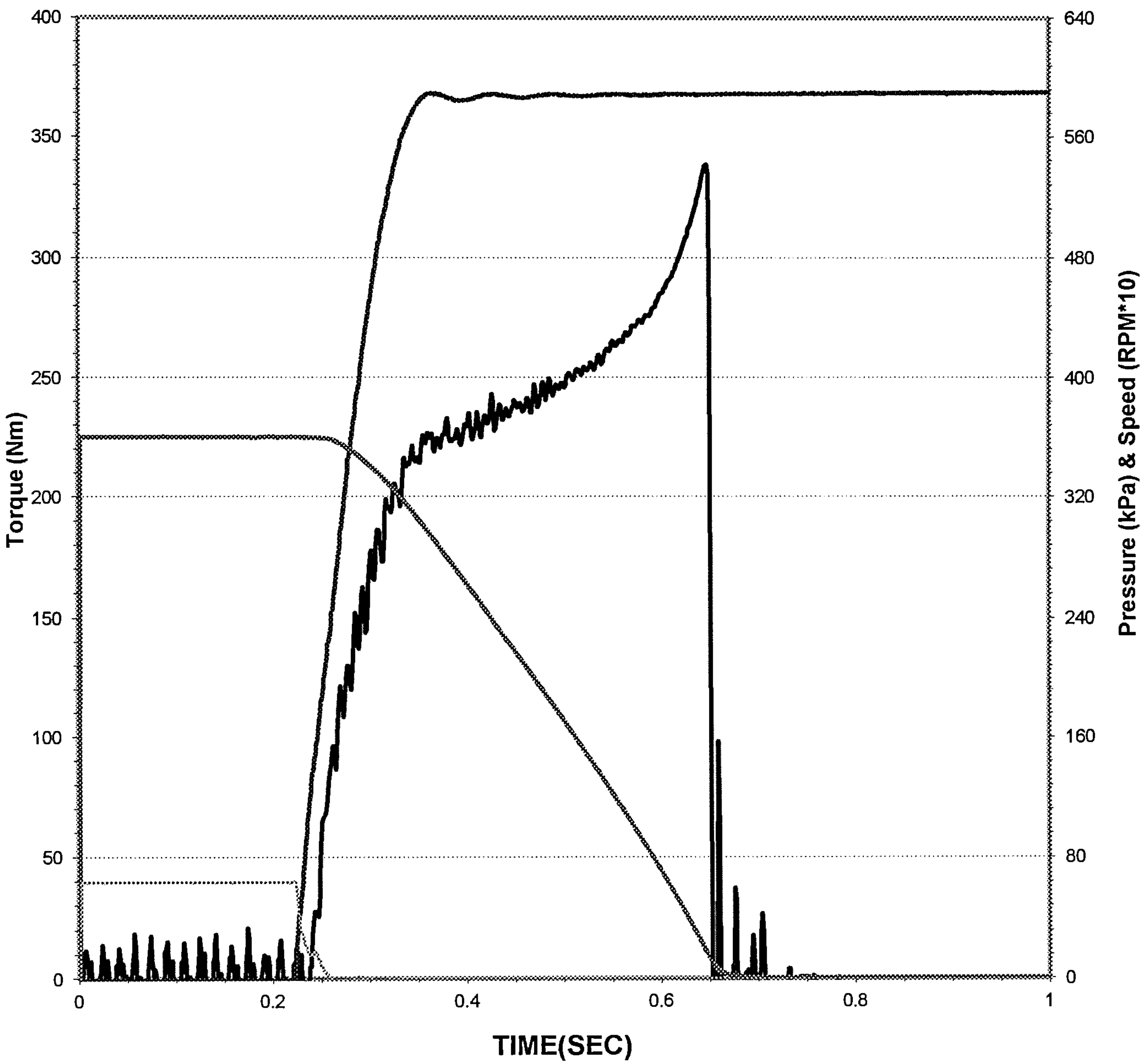
0.2 Sec Dyn:	236 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	333 N*m

Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.162

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	19:52:38
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	2500
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.429 Sec

Torque

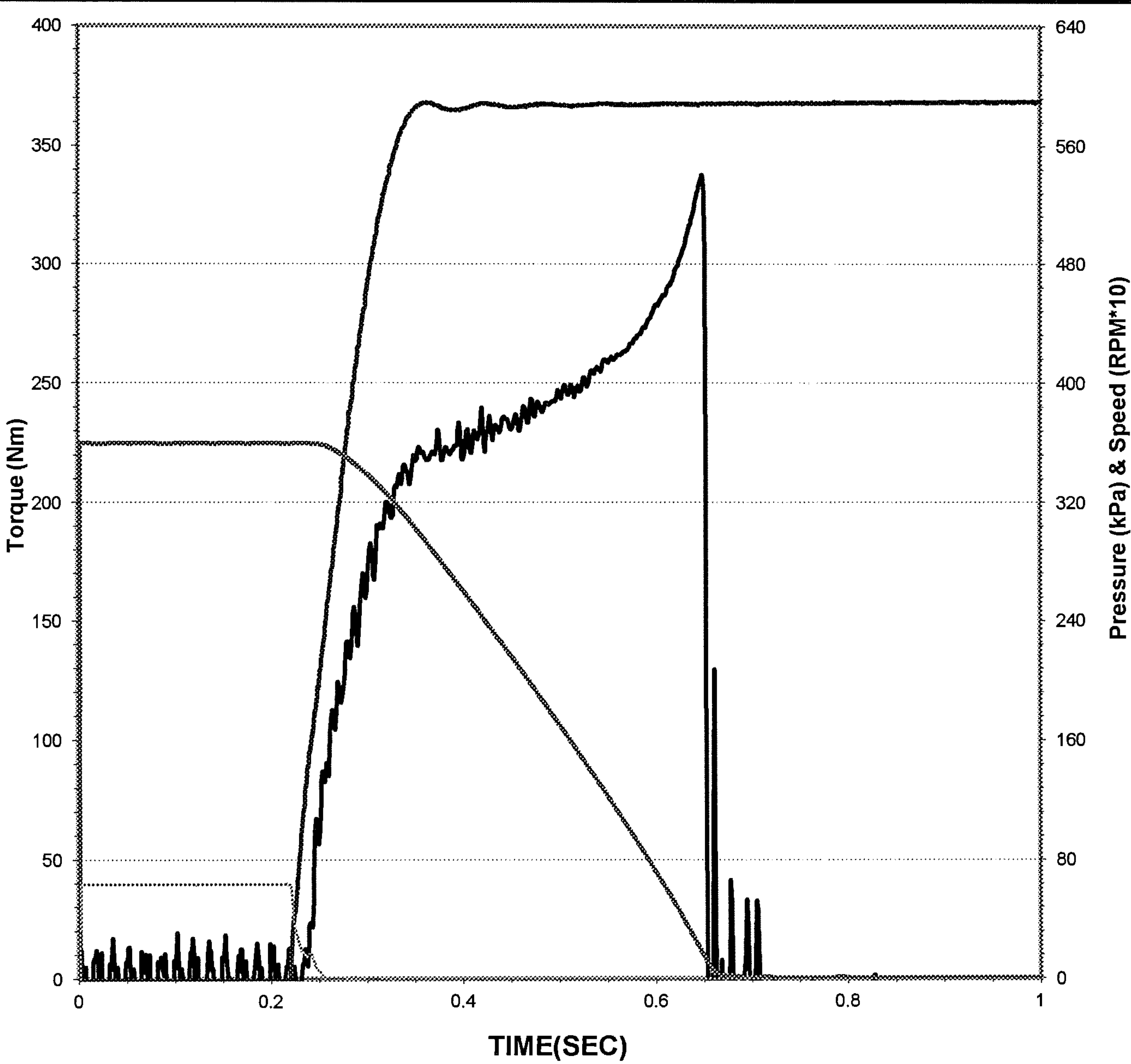
0.2 Sec Dyn:	238 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	339 N*m

Coefficient of Friction

.2 Sec Dyn:	0.116
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.165

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/15/2011
Time of Test:	19:53:09
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	2501
Temperature:	87.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.433 Sec

Torque

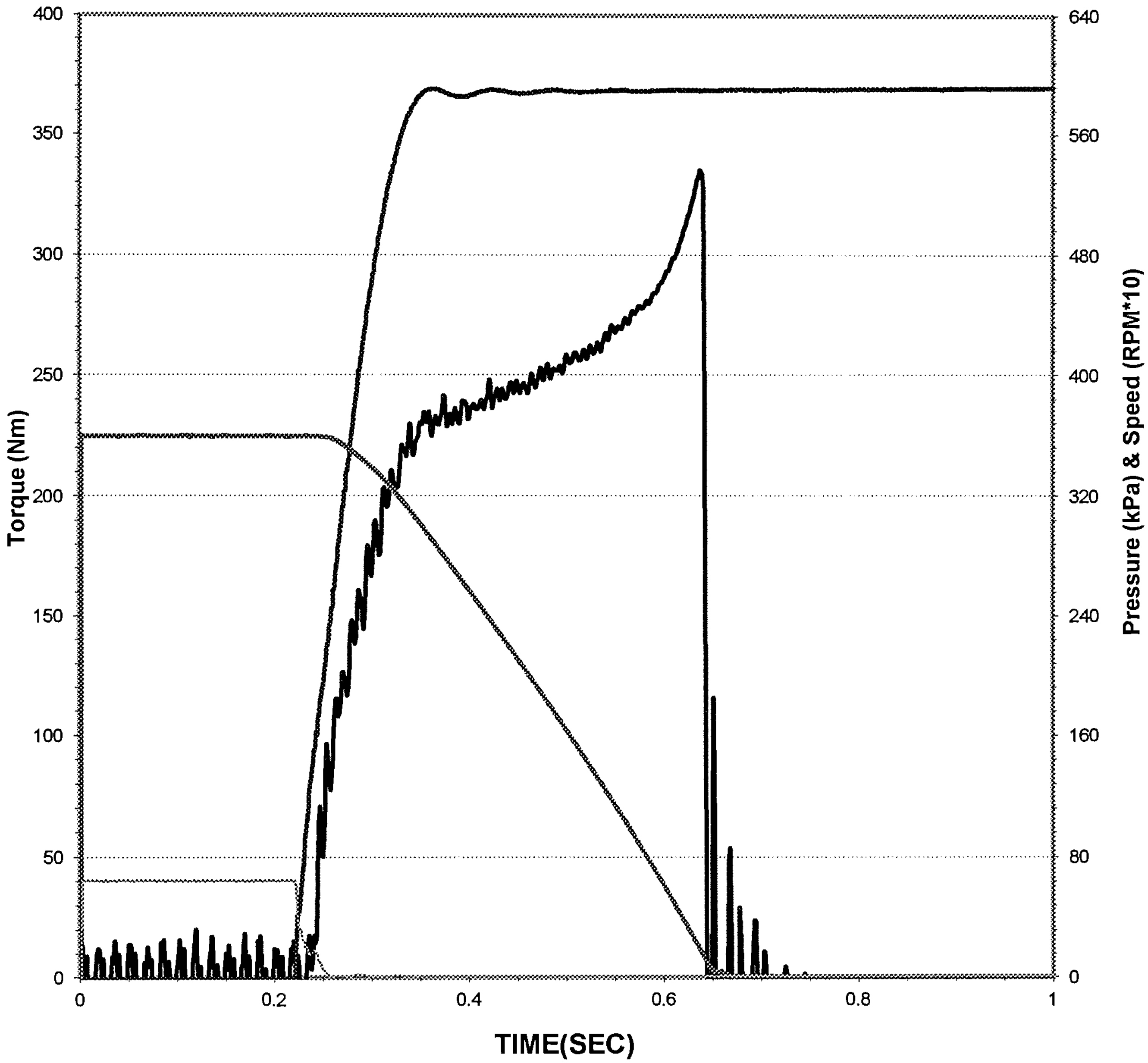
0.2 Sec Dyn:	234 N*m
Midpoint Dyn:	236 N*m
LwSpd Dynamic:	335 N*m

Coefficient of Friction

.2 Sec Dyn:	0.114
Midpoint Dyn:	0.115
LwSpd Dynamic:	0.163

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/16/2011
Time of Test:	6:17:39
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	4999
Temperature:	92.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.422 Sec

Torque

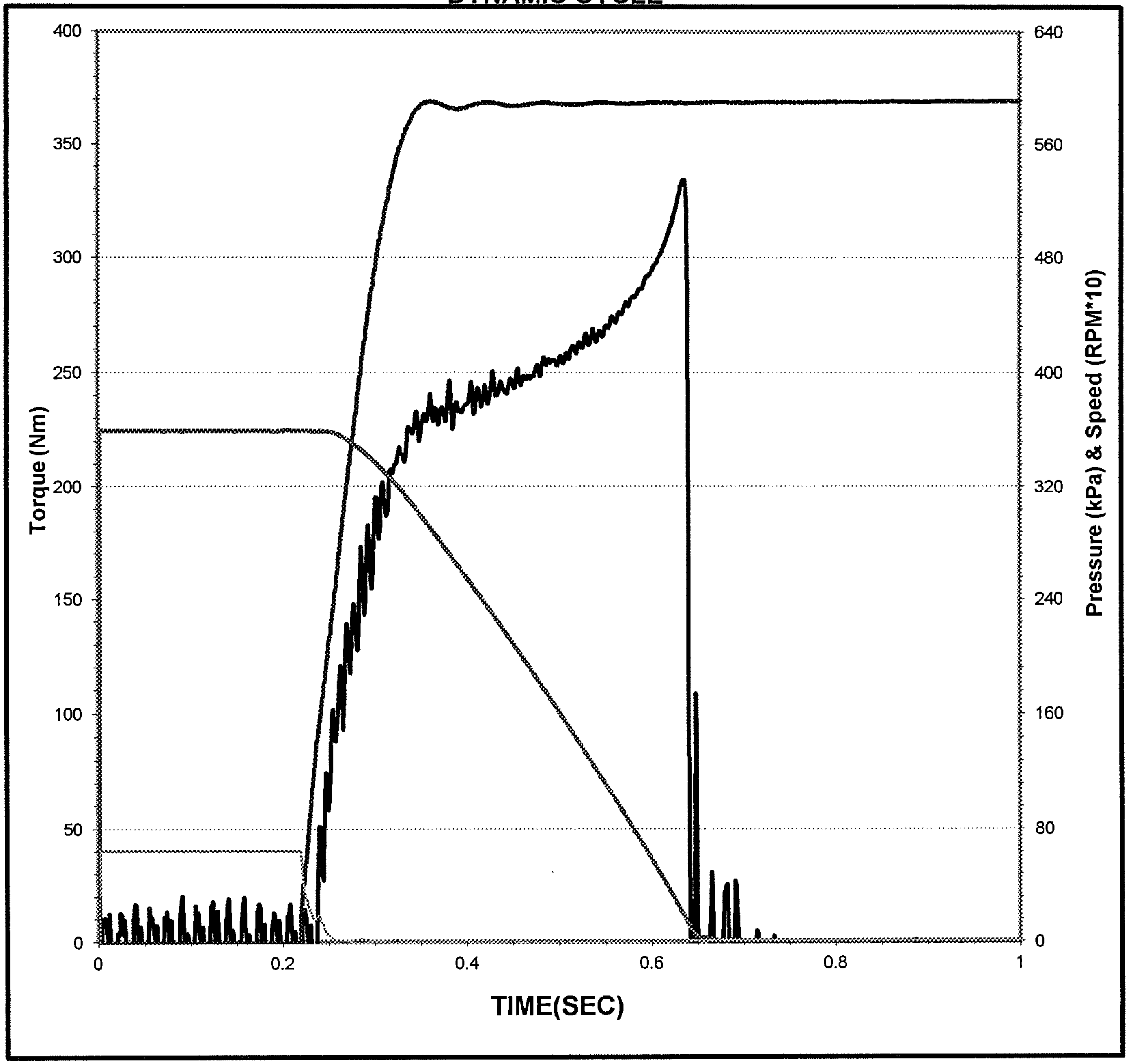
0.2 Sec Dyn:	244 N*m
Midpoint Dyn:	245 N*m
LwSpd Dynamic:	332 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.162

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/16/2011
Time of Test:	6:17:54
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	5000
Temperature:	93.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.422 Sec

Torque

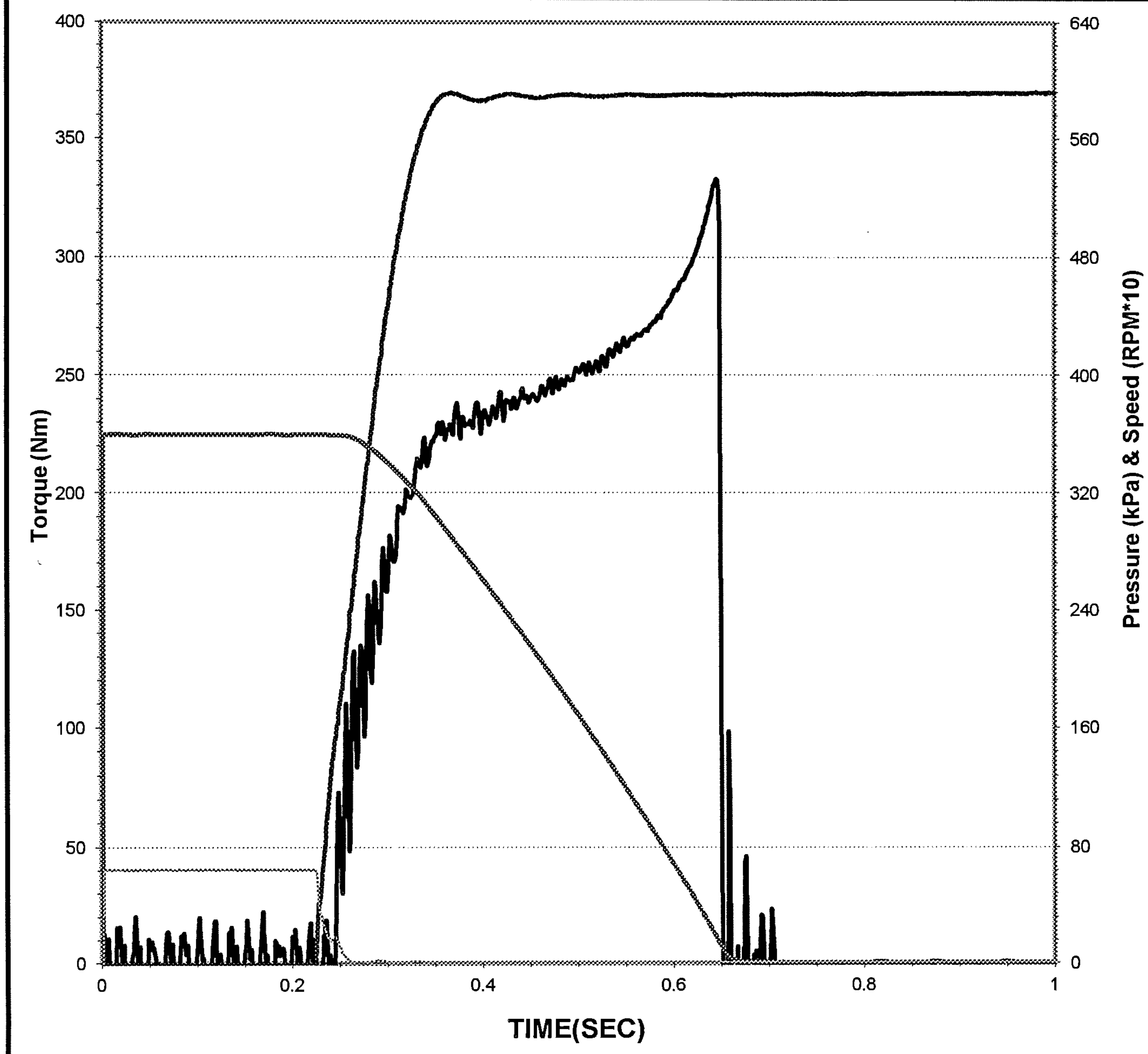
0.2 Sec Dyn:	244 N*m
Midpoint Dyn:	245 N*m
LwSpd Dynamic:	335 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.163

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/16/2011
Time of Test:	6:18:25
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	5001
Temperature:	87.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.425 Sec

Torque

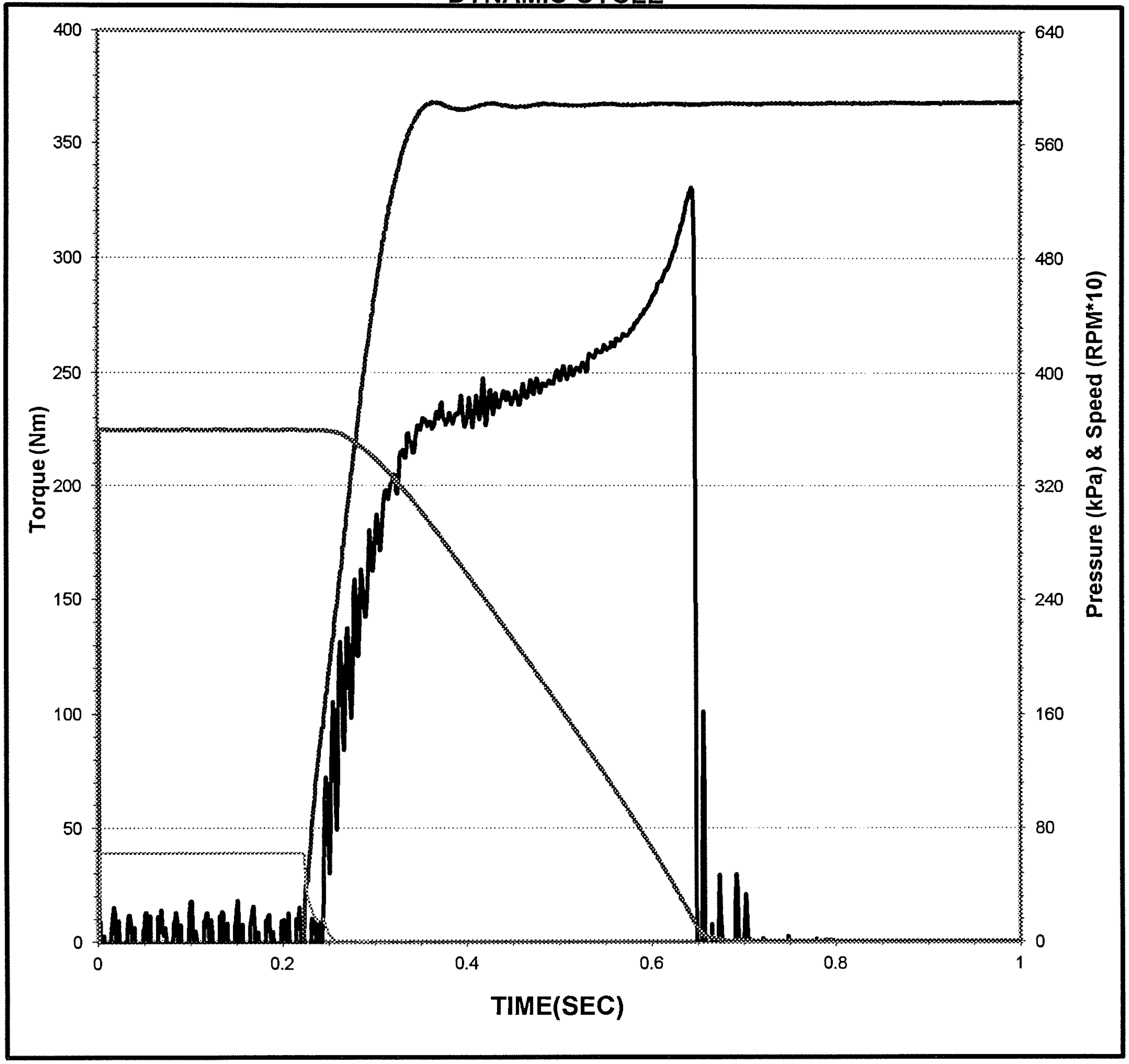
0.2 Sec Dyn:	241 N*m
Midpoint Dyn:	242 N*m
LwSpd Dynamic:	332 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.118
LwSpd Dynamic:	0.162

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/16/2011
Time of Test:	16:42:55
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	7499
Temperature:	92.8 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.426 Sec

Torque

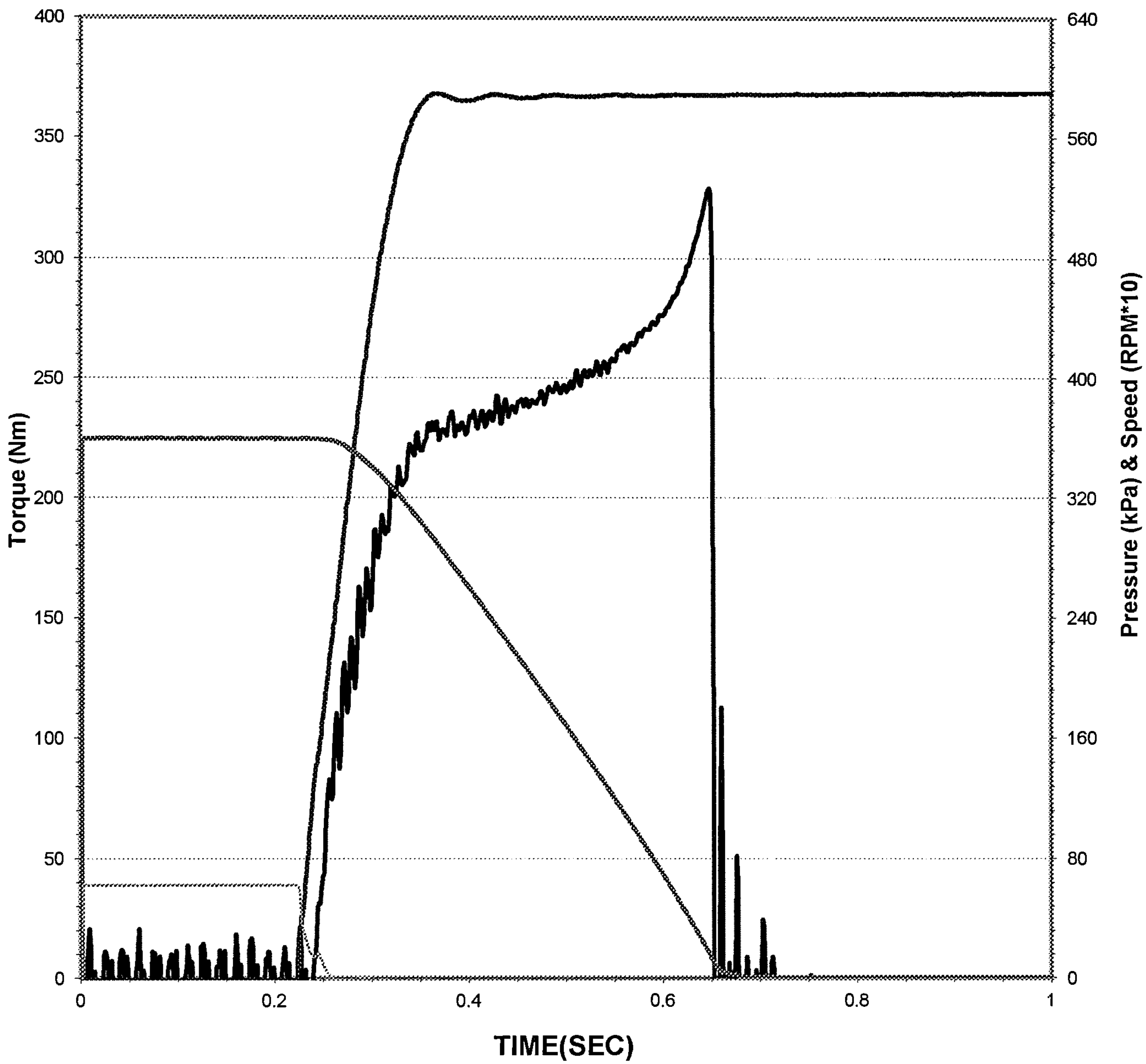
0.2 Sec Dyn:	242 N*m
Midpoint Dyn:	242 N*m
LwSpd Dynamic:	330 N*m

Coefficient of Friction

.2 Sec Dyn:	0.118
Midpoint Dyn:	0.118
LwSpd Dynamic:	0.161

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/16/2011
Time of Test:	16:43:10
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	7500
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.428 Sec

Torque

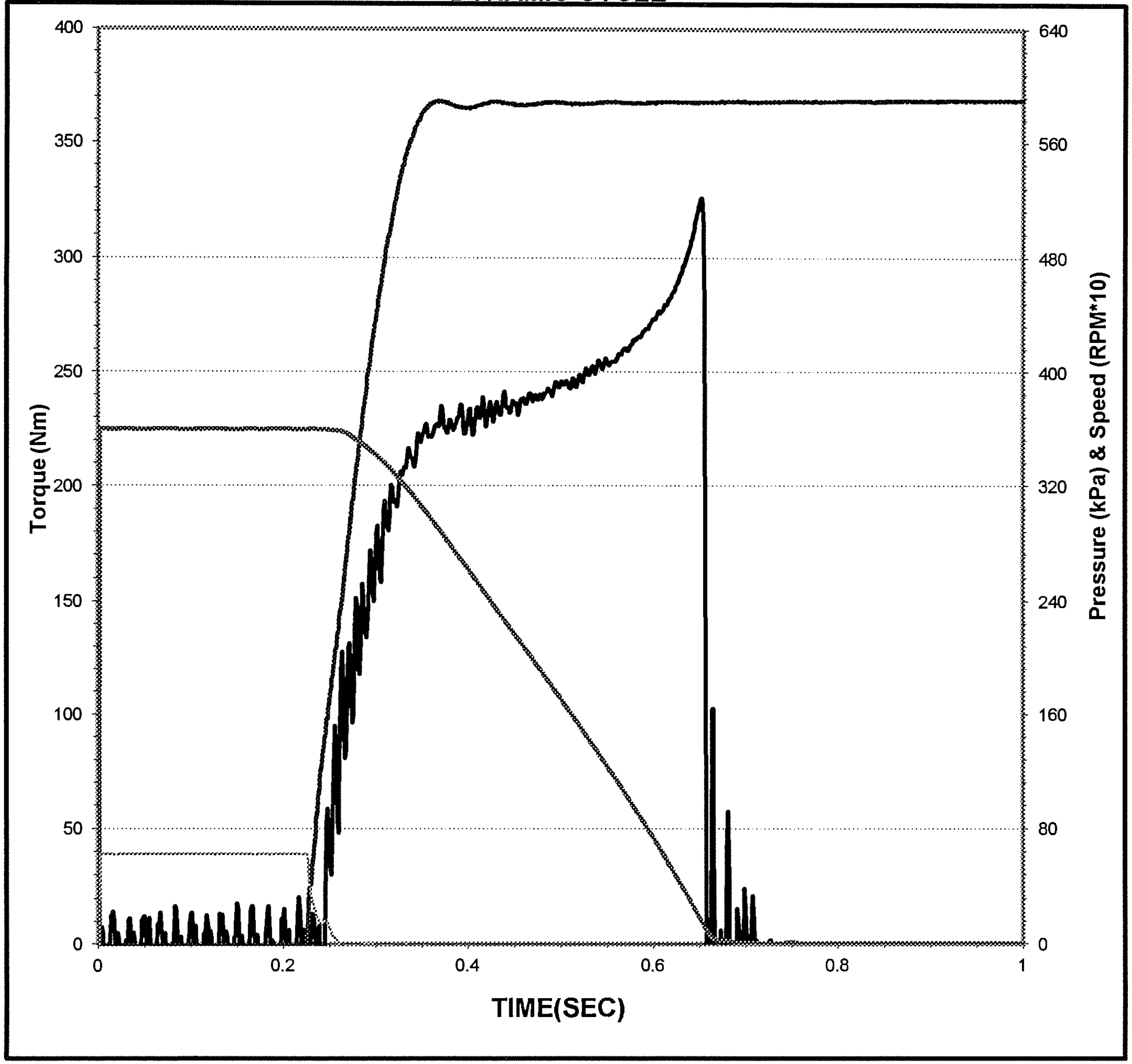
0.2 Sec Dyn:	240 N*m
Midpoint Dyn:	241 N*m
LwSpd Dynamic:	326 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.159

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/16/2011
Time of Test:	16:43:41
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	7501
Temperature:	87.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.431 Sec

Torque

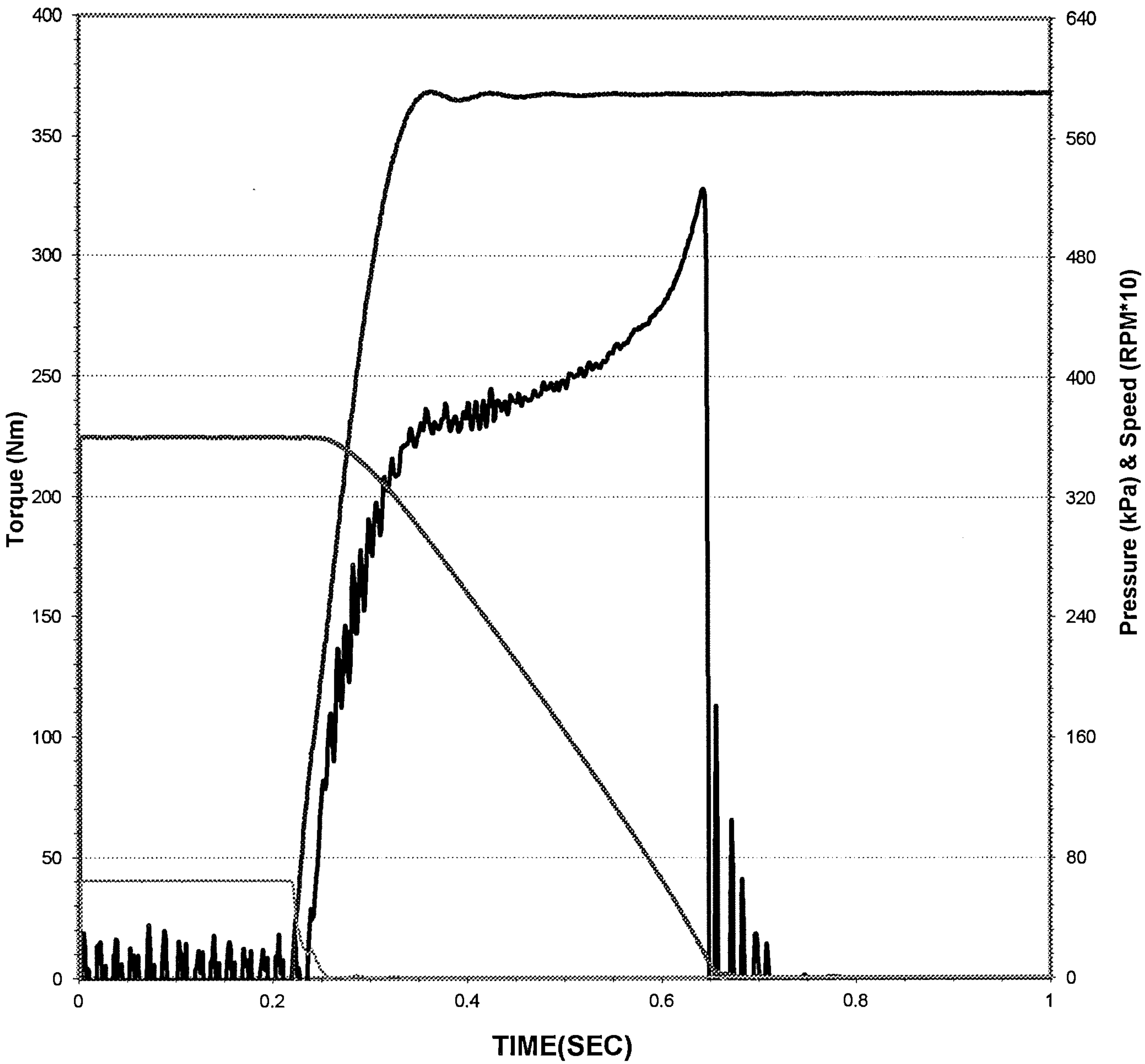
0.2 Sec Dyn:	237 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	320 N*m

Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.156

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/17/2011
Time of Test:	3:07:57
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	9998
Temperature:	93.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.428 Sec

Torque

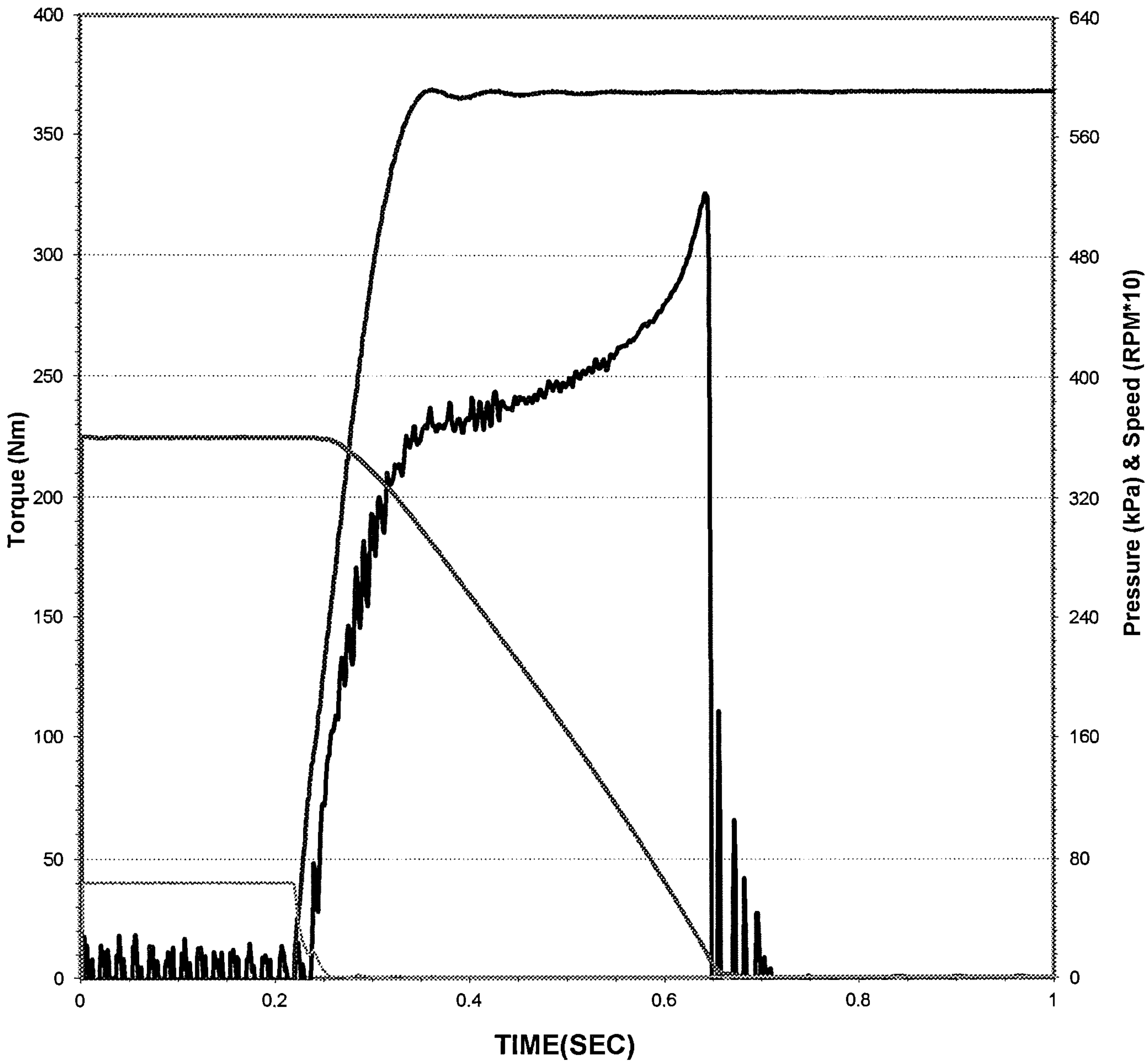
0.2 Sec Dyn:	239 N*m
Midpoint Dyn:	241 N*m
LwSpd Dynamic:	323 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.157

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/17/2011
Time of Test:	3:08:12
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	9999
Temperature:	92.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.428 Sec

Torque

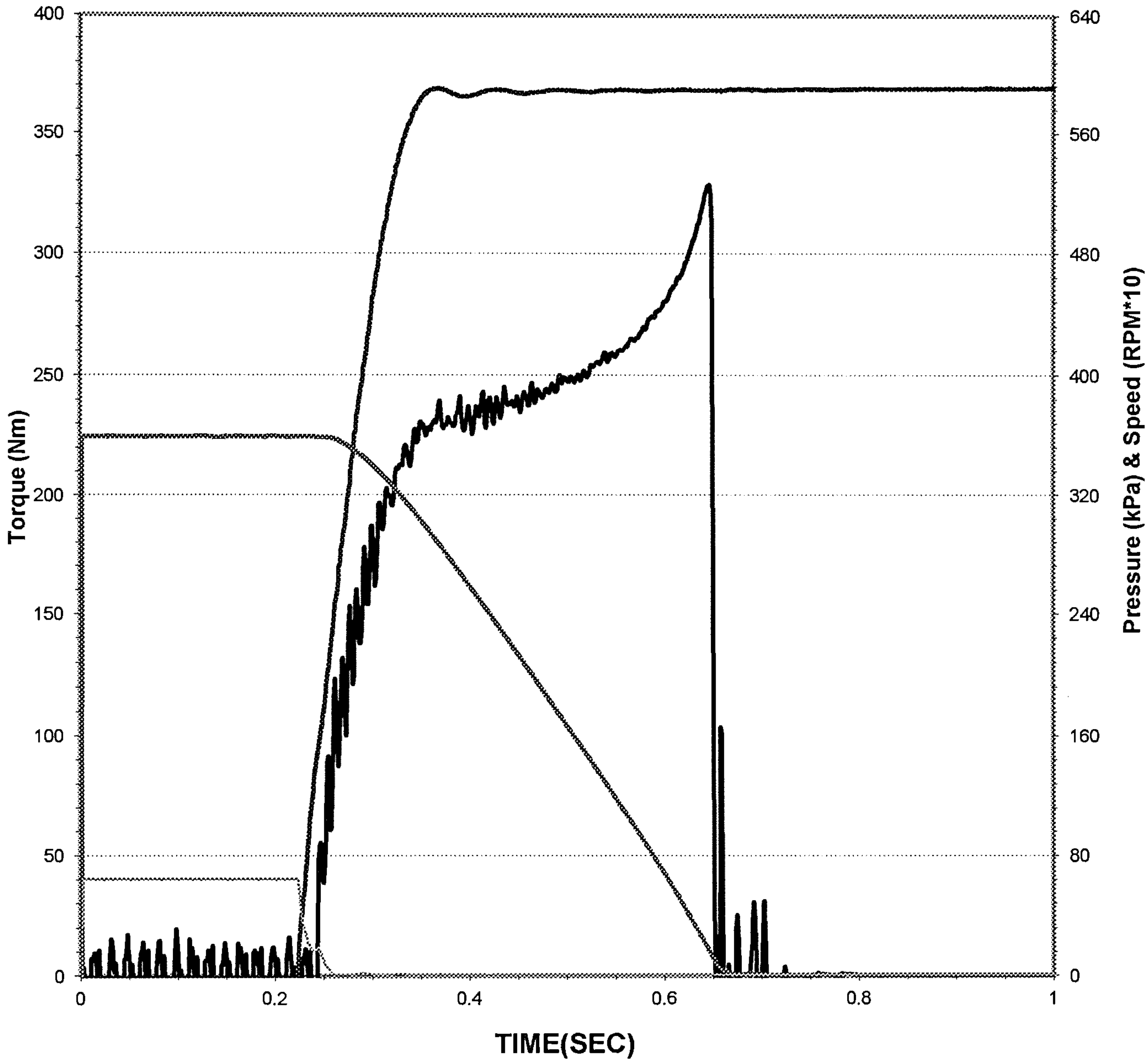
0.2 Sec Dyn:	239 N*m
Midpoint Dyn:	240 N*m
LwSpd Dynamic:	322 N*m

Coefficient of Friction

.2 Sec Dyn:	0.116
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.157

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	10/17/2011
Time of Test:	3:08:27
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	10000
Temperature:	92.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.427 Sec

Torque

0.2 Sec Dyn:	239 N*m
Midpoint Dyn:	241 N*m
LwSpd Dynamic:	328 N*m

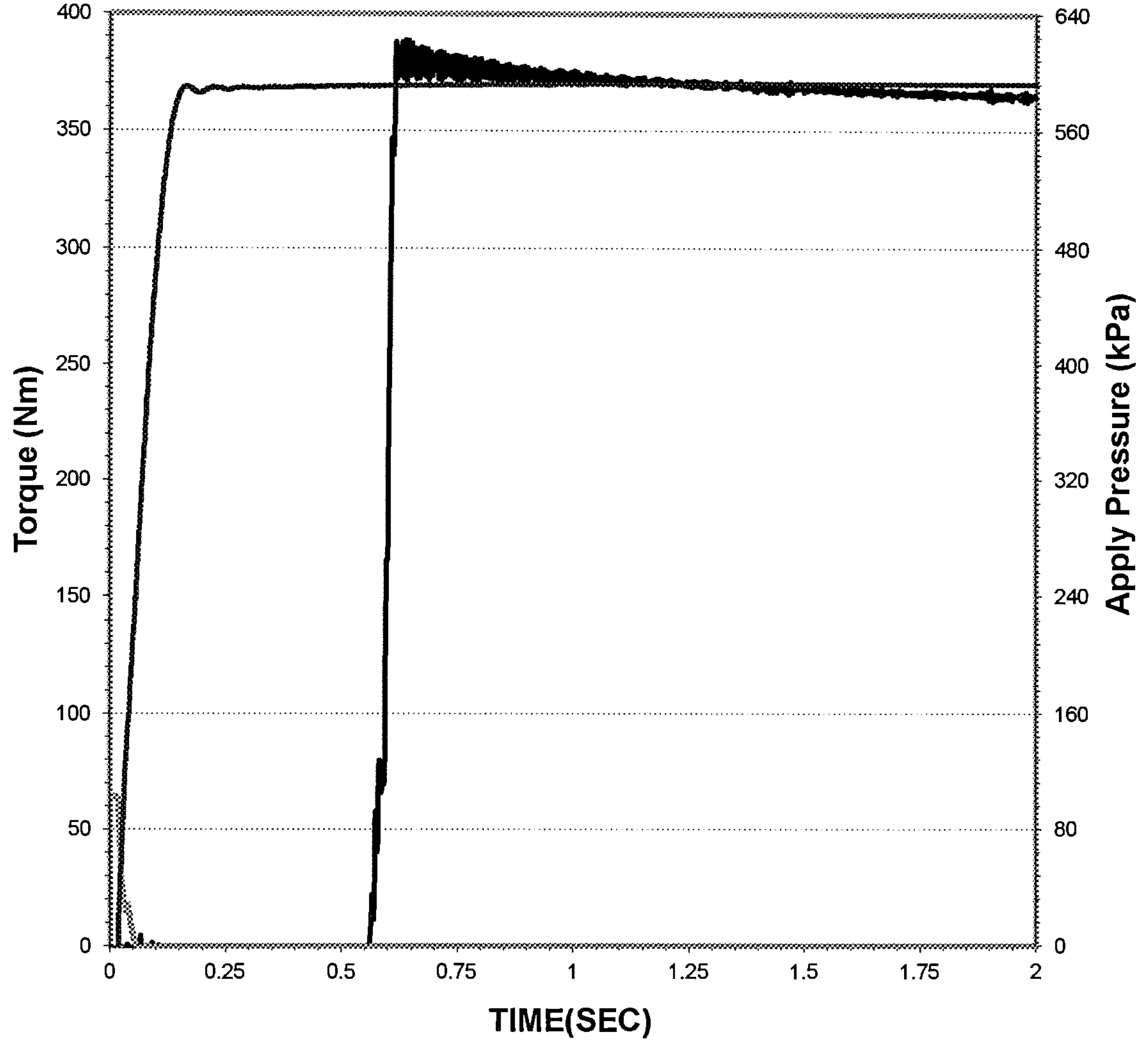
Coefficient of Friction

.2 Sec Dyn:	0.116
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.160

STATIC TRACES

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 9:29:19

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 10

STATIC CYCLE

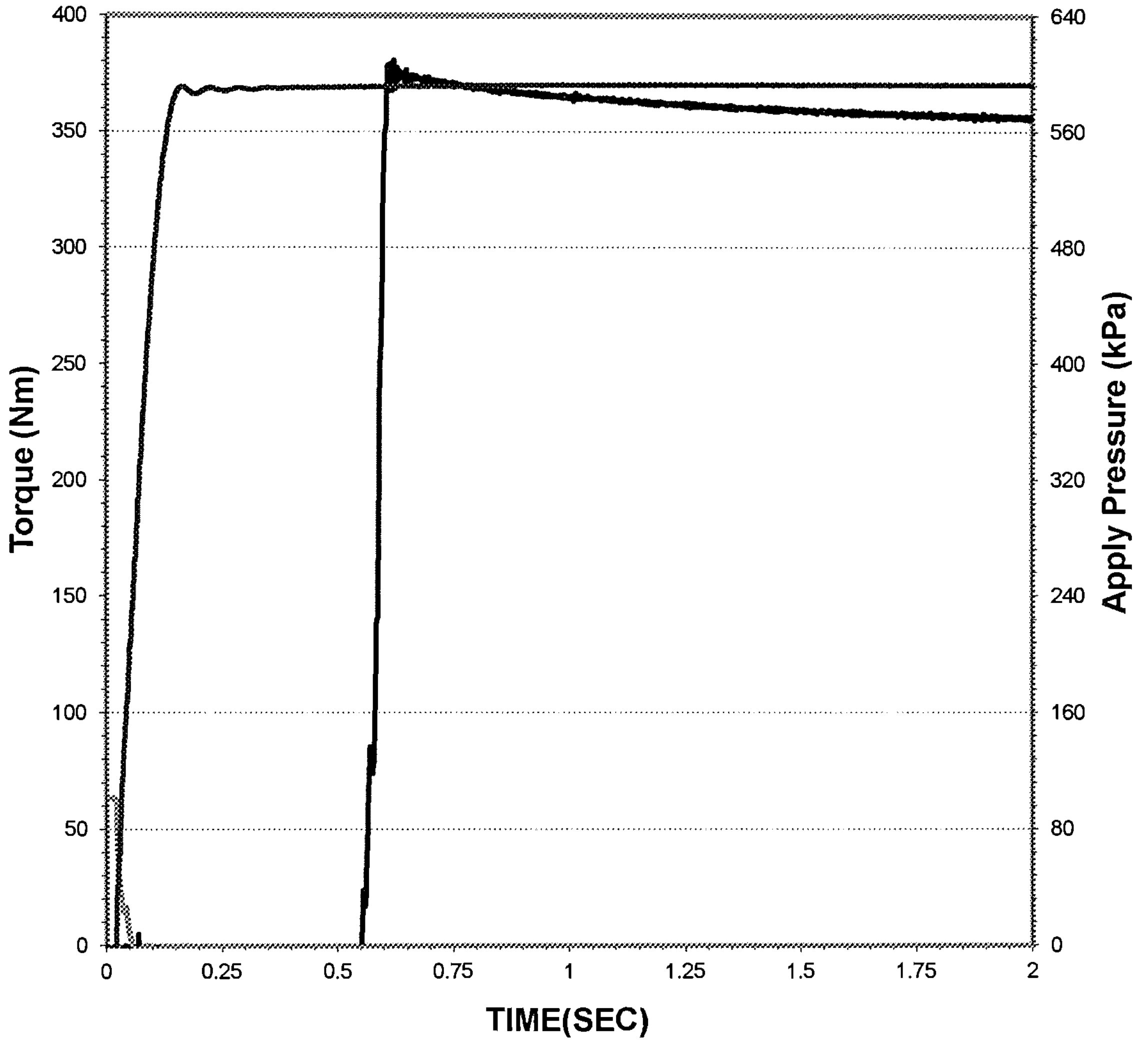
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 391 Nm
.25 Second: 375 Nm

Coefficient of Friction
Static Peak: 0.191
.25 Second: 0.182

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 9:52:05

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 100

STATIC CYCLE

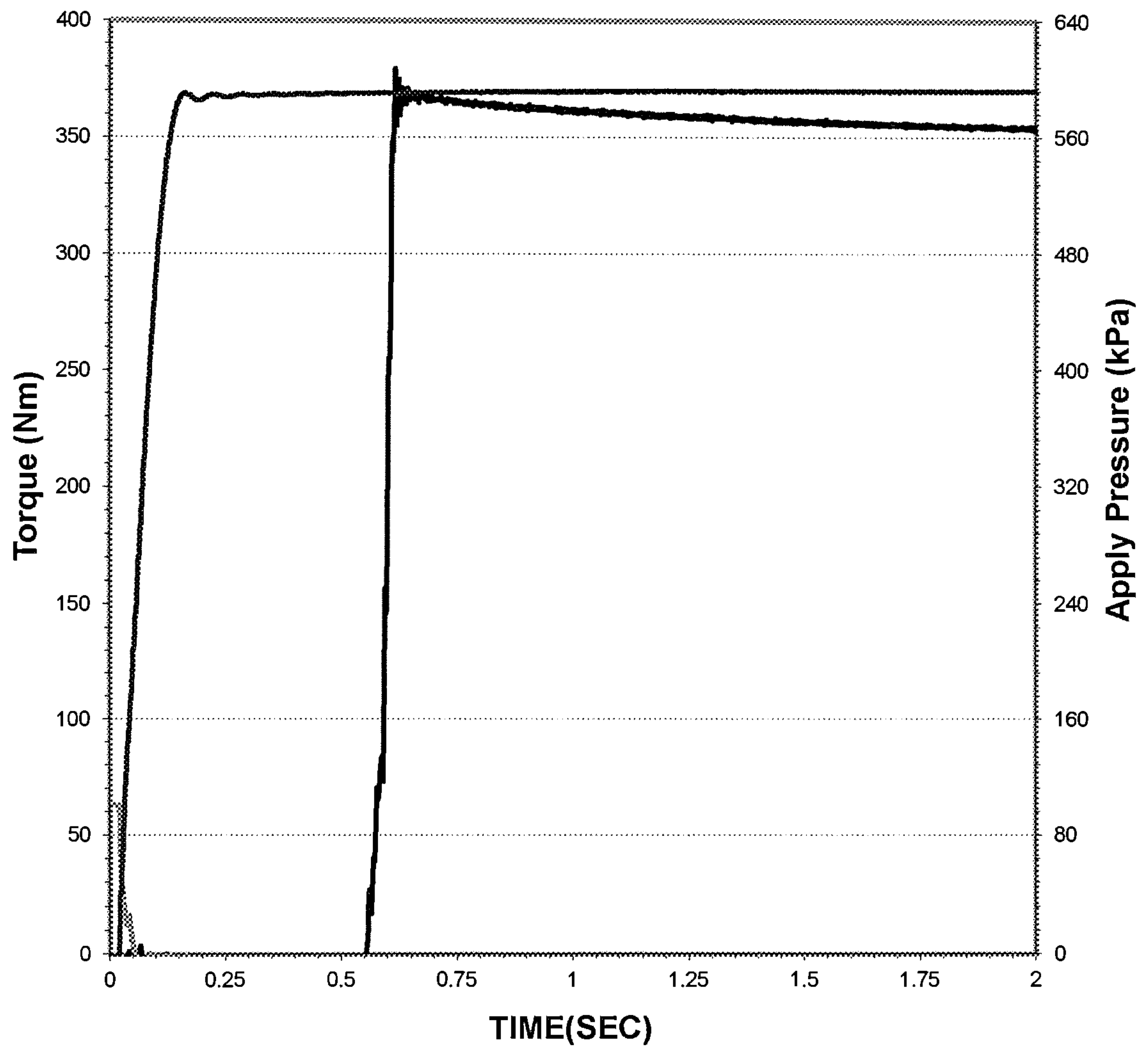
Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 383 Nm
.25 Second: 371 Nm

Coefficient of Friction
Static Peak: 0.187
.25 Second: 0.181

ALLISON C-4 PAPER DATA

STATIC CYCLE



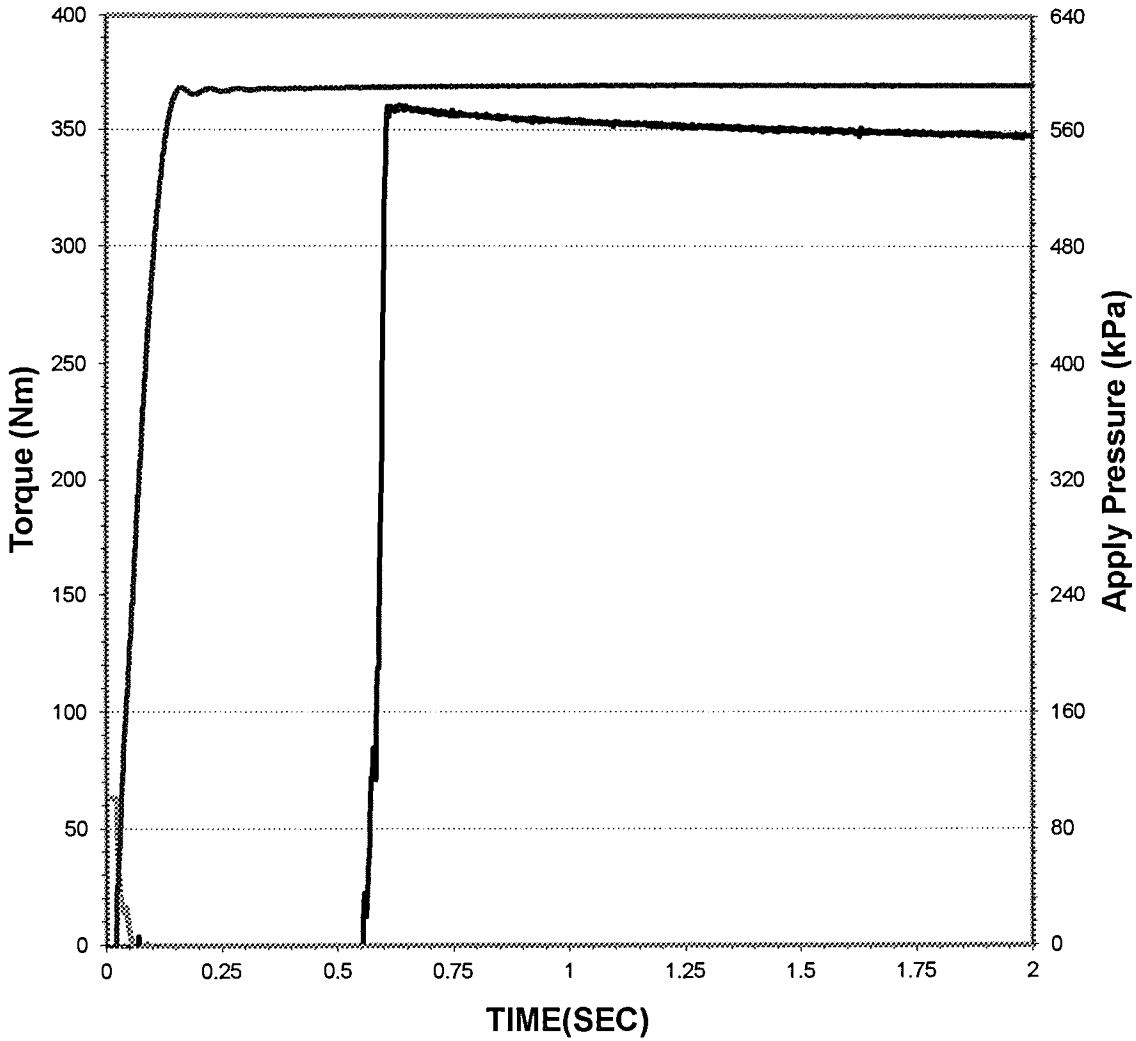
Date of Test:	10/15/2011
Time of Test:	11:32:21
Test Number:	C2-4-1574
Fluid Code:	LO271510
Cycle Number:	500

STATIC CYCLE

Apply Pressure:	
At .25 Second:	589 kPa
Torque	
Static Peak:	383 Nm
.25 Second:	368 Nm
Coefficient of Friction	
Static Peak:	0.186
.25 Second:	0.179

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 13:37:37

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 1000

STATIC CYCLE

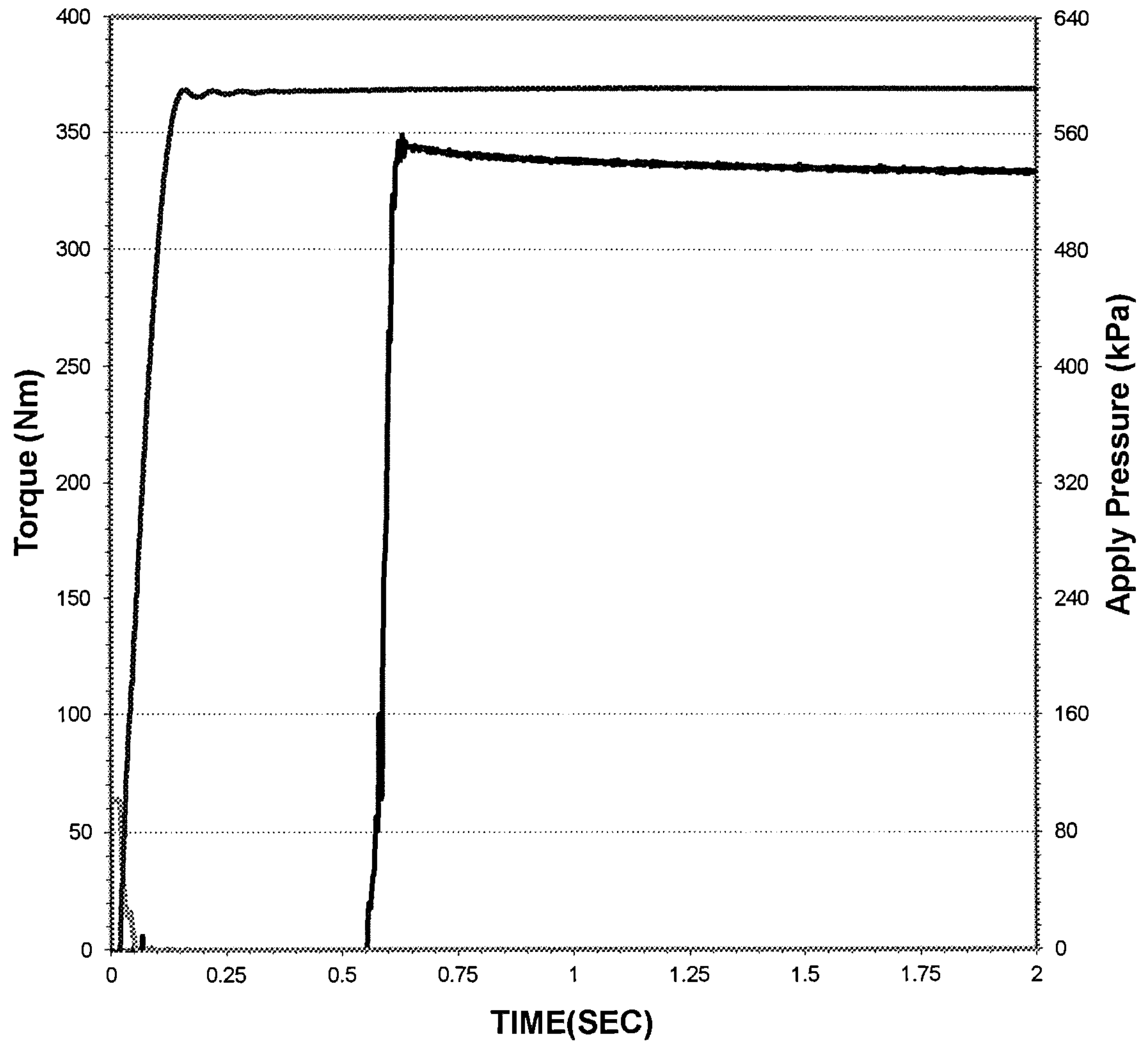
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 365 Nm
.25 Second: 359 Nm

Coefficient of Friction
Static Peak: 0.178
.25 Second: 0.175

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/15/2011

Time of Test: 19:52:54

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 2500

STATIC CYCLE

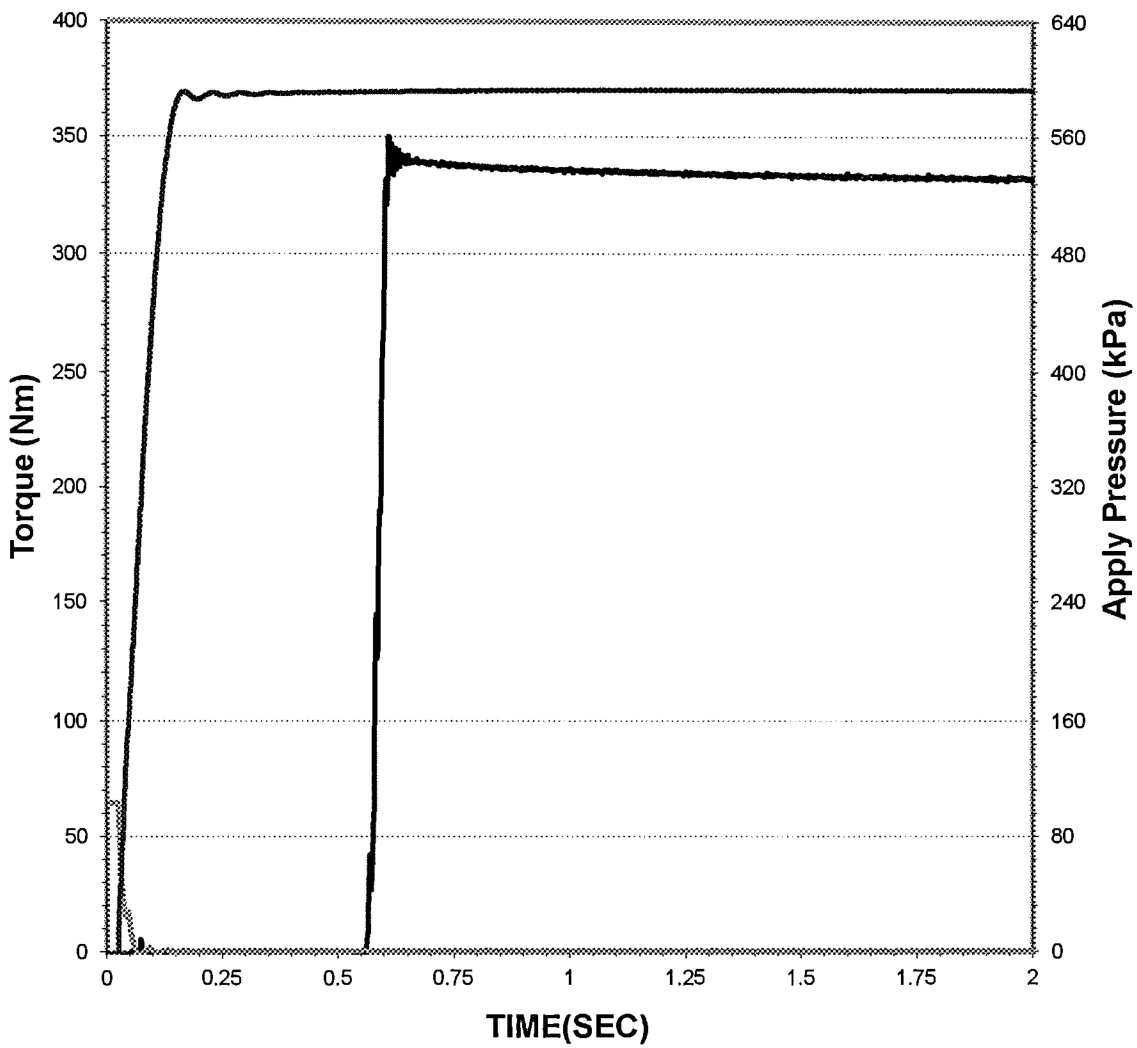
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 352 Nm
.25 Second: 343 Nm

Coefficient of Friction
Static Peak: 0.172
.25 Second: 0.167

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/16/2011

Time of Test: 6:18:10

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 5000

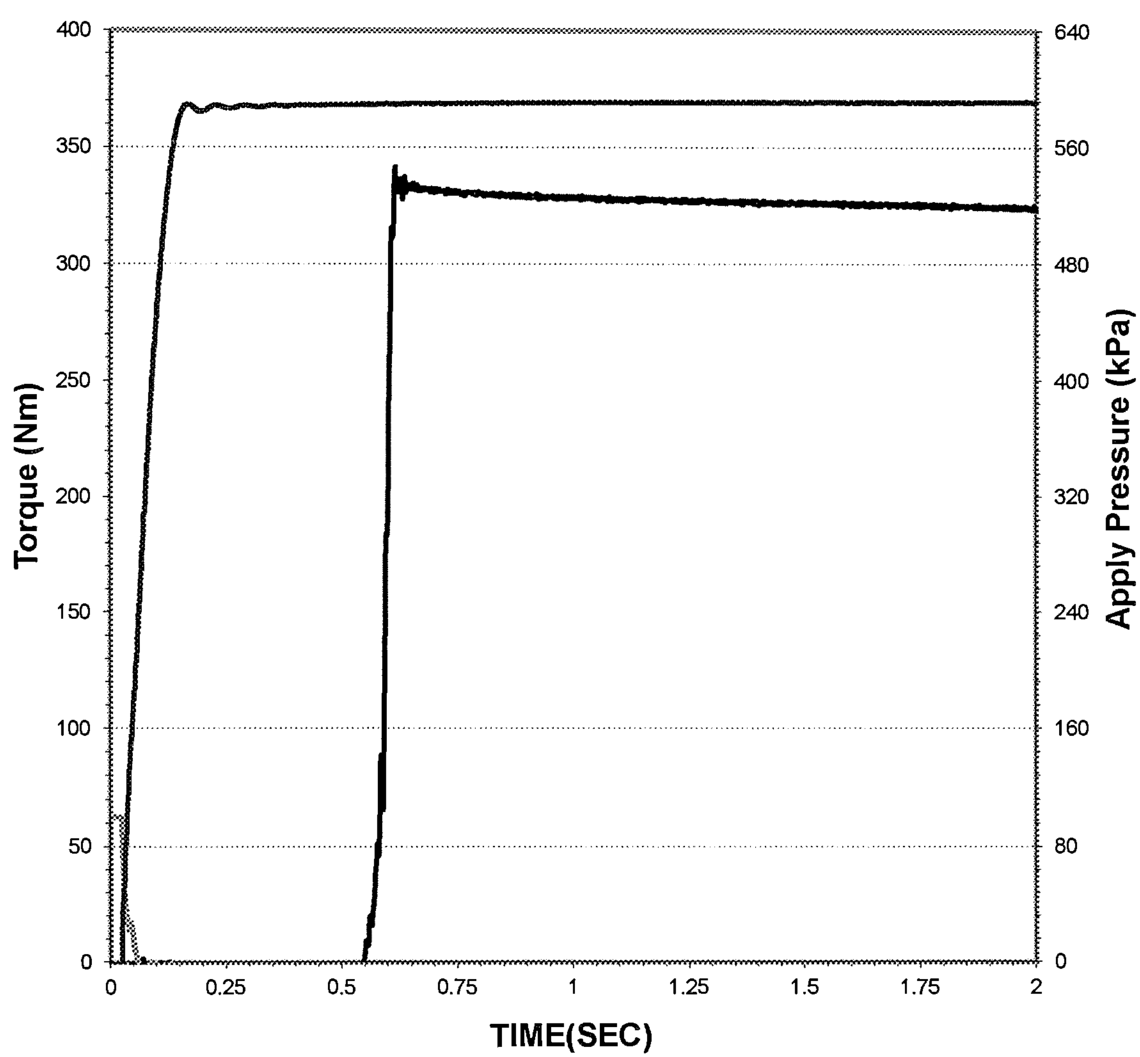
STATIC CYCLE

Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 353 Nm
.25 Second: 340 Nm

Coefficient of Friction
Static Peak: 0.172
.25 Second: 0.166

ALLISON C-4 PAPER DATA



Date of Test: 10/16/2011

Time of Test: 16:43:26

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 7500

STATIC CYCLE

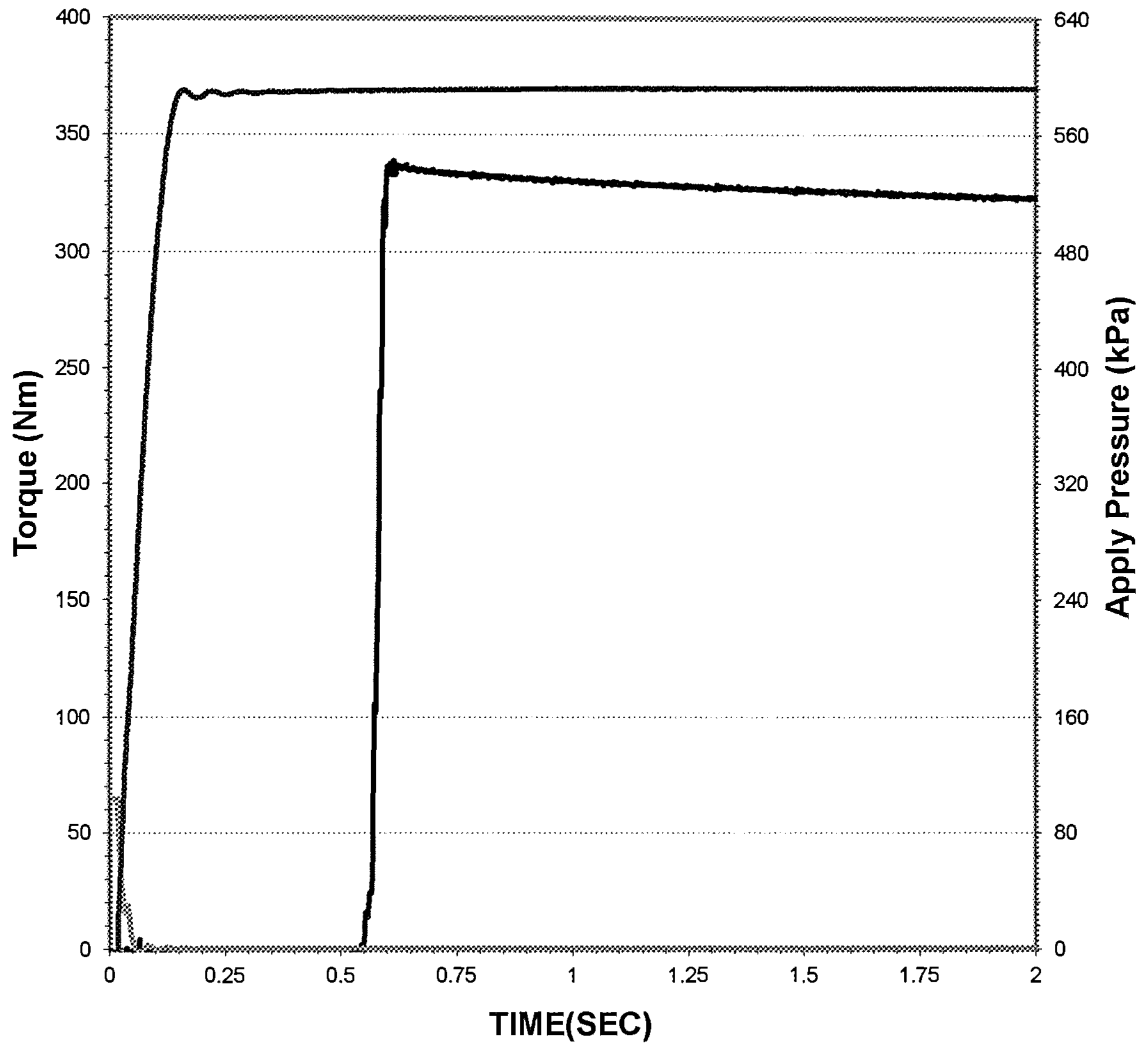
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 345 Nm
.25 Second: 334 Nm

Coefficient of Friction
Static Peak: 0.168
.25 Second: 0.163

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 10/17/2011

Time of Test: 3:08:43

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 10000

STATIC CYCLE

Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 341 Nm
.25 Second: 335 Nm

Coefficient of Friction
Static Peak: 0.166
.25 Second: 0.163

APPENDIX – E1
CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
LO268869

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Conducted for

ARMY LAB

Oil Code:
LO268869

Test Number:
VC70-A-163-J

October 19, 2011

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: ARMY LAB

Test start date: 10/18/2011
End of test date: 10/19/2011
Oil Code: LO268869

Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:		P		F			
Dynamic Coefficient Vs. Load:		P		F			
Dynamic Coefficient Vs. Speed:		P		F			
Energy Limit:		P		P			
Static Coefficient Vs. Load:		P		F			
Static Coefficient Vs. Speed:		P		F			
Energy Limit:		P		P			
Total Wear:		0.016		0.029			
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand. The results are compared to TO-4 testing limits. 2009 Batch parts were used for this sequence.

F = Fail
P = Pass
N/A = Not Applicable

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO268869 / LO-268869

Test name:	A-163-J
Test date:	10/18/11
Test description:	J MACHINE LO268869
Oil type:	LO268869 / LO-268869
Viscosity:	N/A
Miscellaneous:	
Software version:	1.40

Run name & desc:	J0508336 - LO268869
Run date:	08/28/11
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J" MACHINE OIL TEST LO268869 / LO-268869
Sequence name:	SEQ1220
Remarks:	Use 1Y0709 Disc and 8E4095 Plate
Number of cycles run:	1097

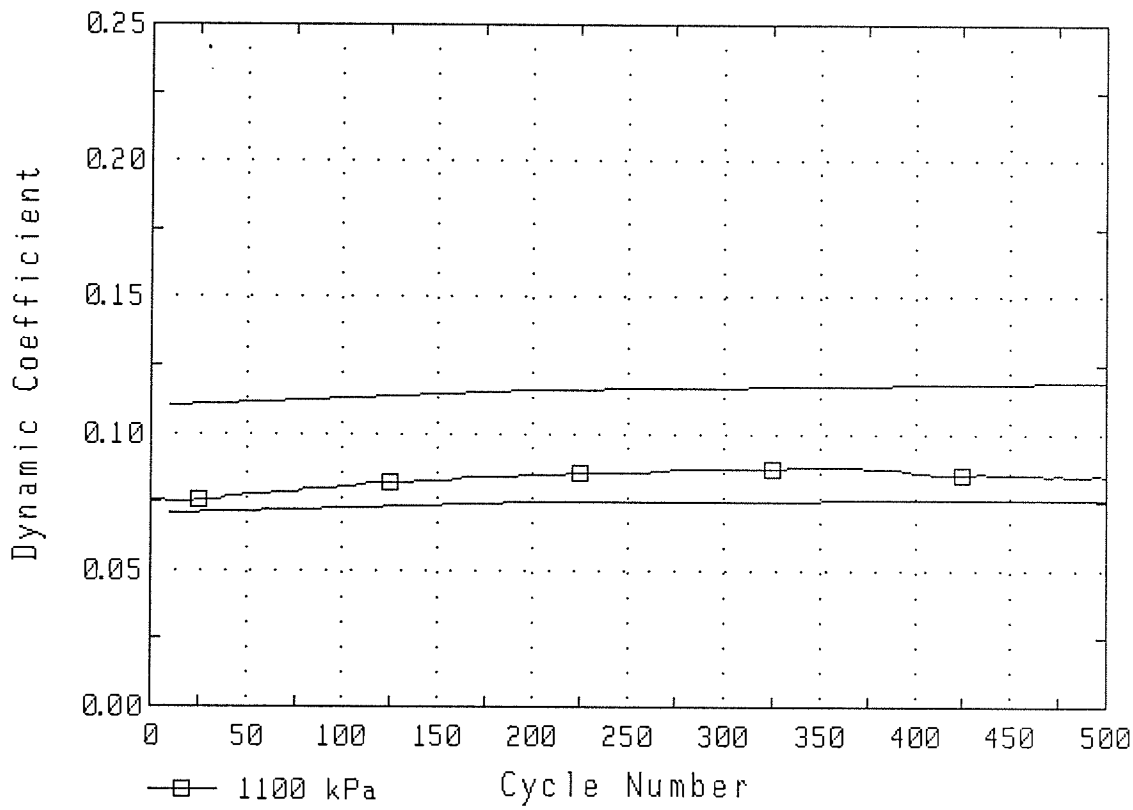
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 N-m-s^2

Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	007080C800012
Remarks:	SINTERED BRONZE

Plate name & desc:	8E4095 - Steel Plate
Surface:	0.70 to 1.00 micron Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	007080C800012
Remarks:	0.80 SURFACE FINISH

Report limit name:	LIM1220 - Reference run: J0508081
Limit file generated:	10/19/11
Report format name:	REP1220 - SINTERED BRONZE

Test: A-163-J Run: J0508336 Started on 08/28/11 at 07:25

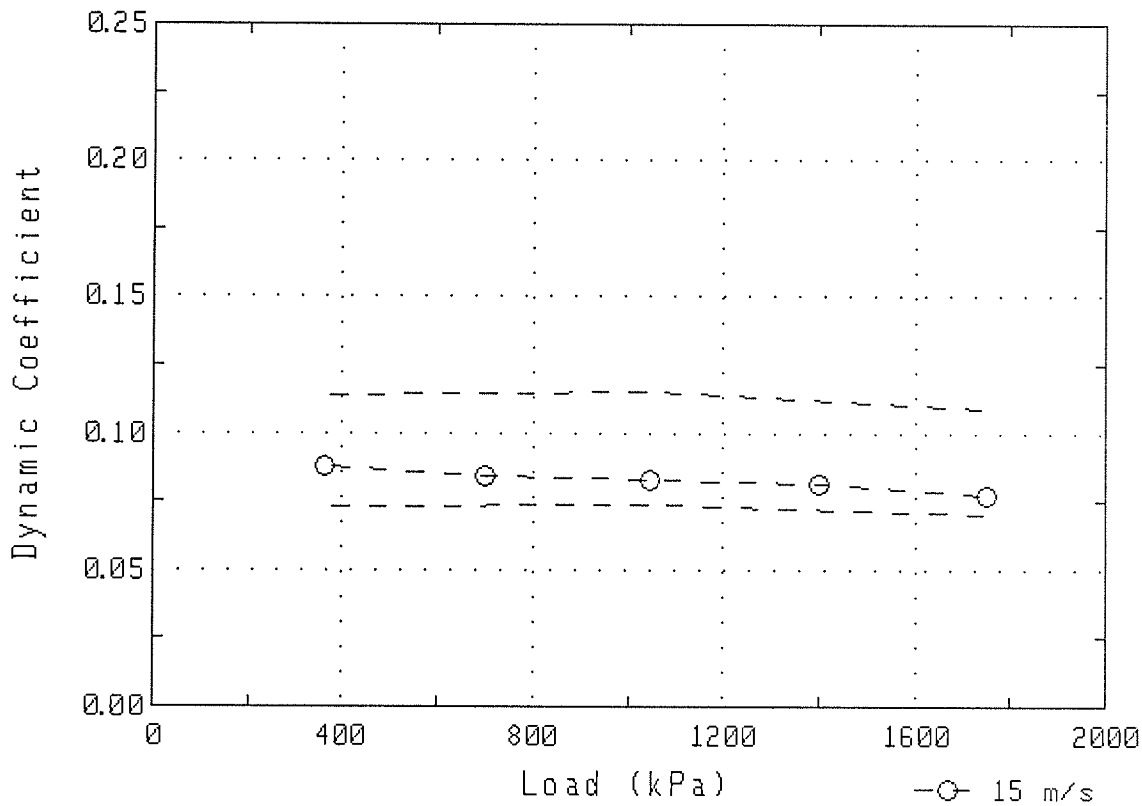


1Y0709 DISC
THICKNESS

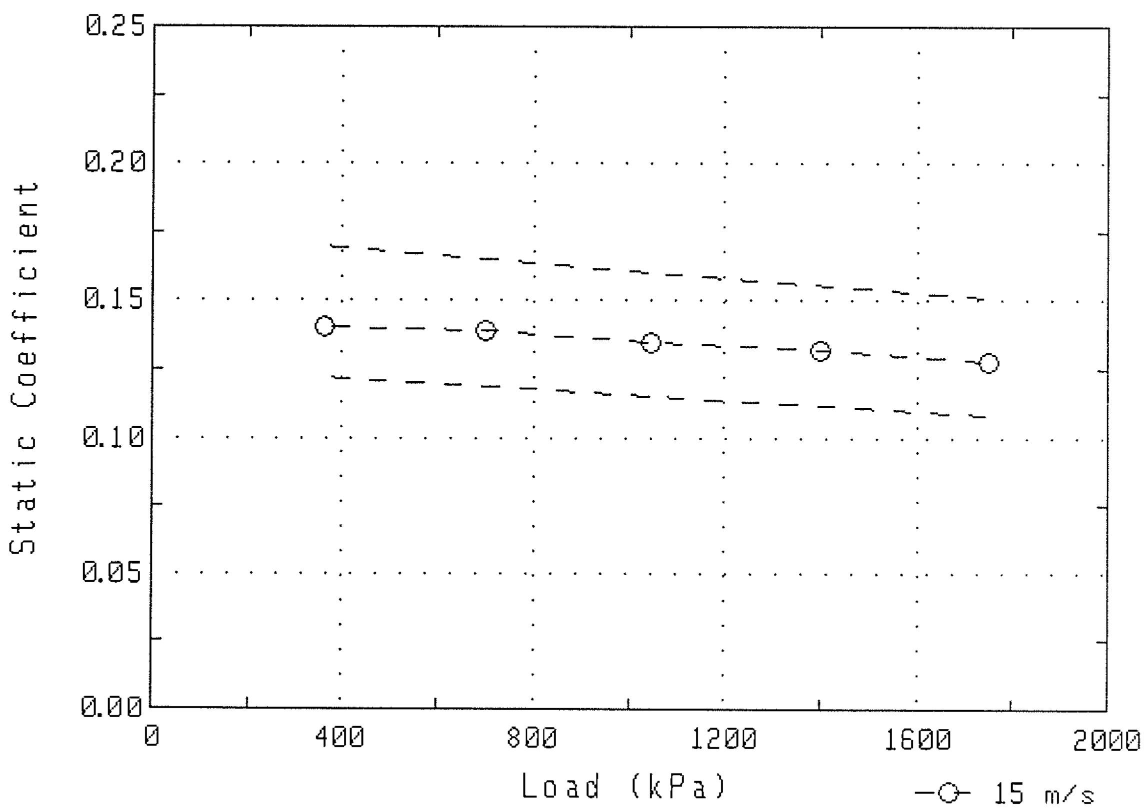
Loc	Outer Diameter M1	M2	M3	Inner Diameter M1	M2	M3
1	4.96	4.95	4.94	4.96	4.95	4.94
2	4.96	4.95	4.94	4.96	4.94	4.94
3	4.97	4.95	4.95	4.96	4.95	4.95
4	4.97	4.95	4.95	4.96	4.95	4.95
5	4.96	4.95	4.95	4.96	4.95	4.95
6	4.96	4.95	4.95	4.96	4.94	4.94
Avg	4.96	4.95	4.95	4.96	4.95	4.94

Compression set average wear: 0.013
M2 - M3 average Wear: 0.003

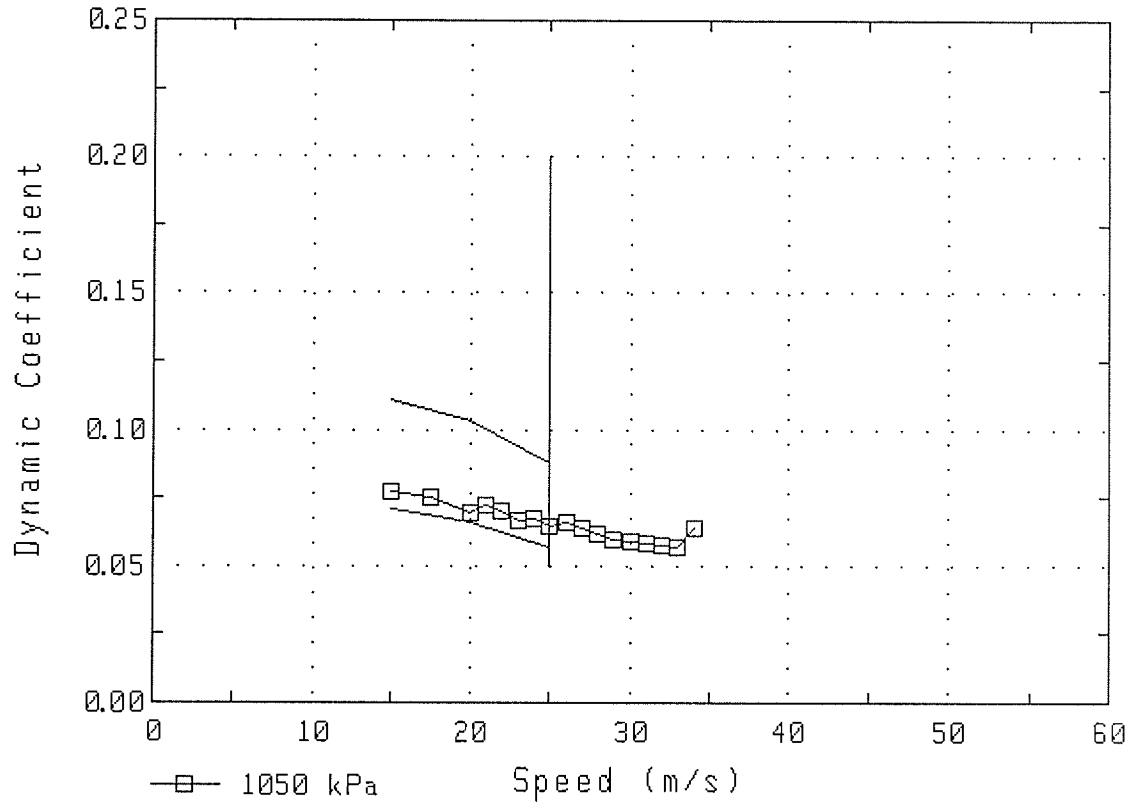
Total Wear (all measurements in mm): 0.016

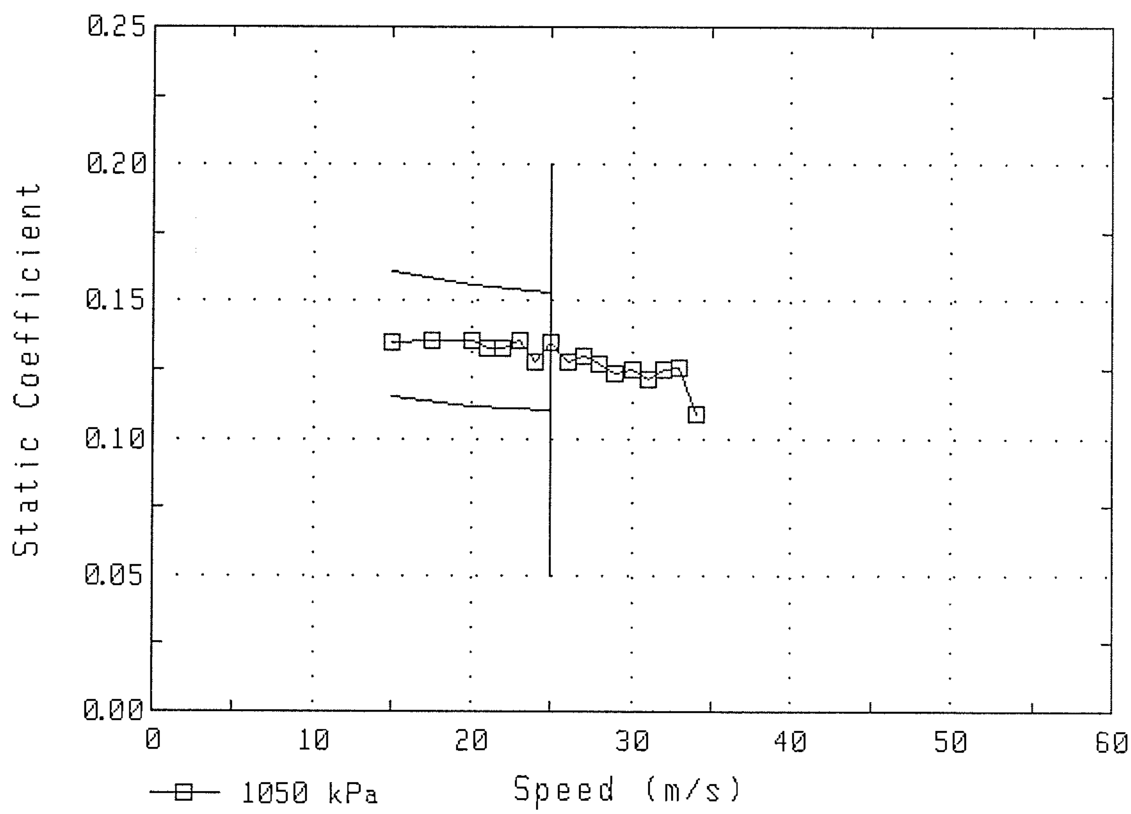


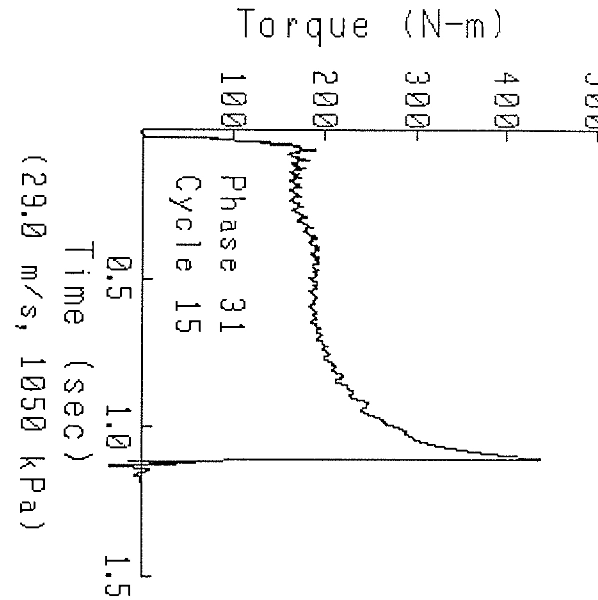
Dynamic Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

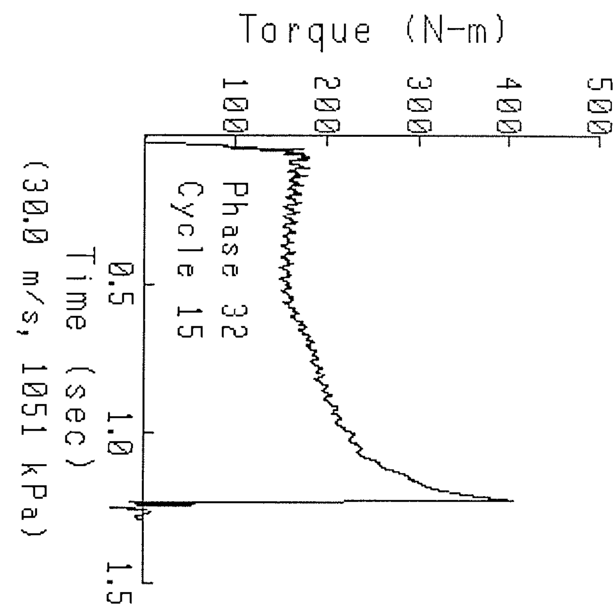


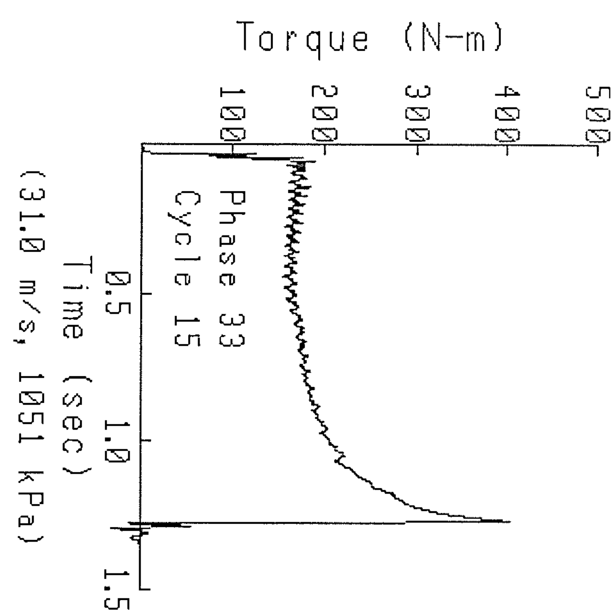
Static Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

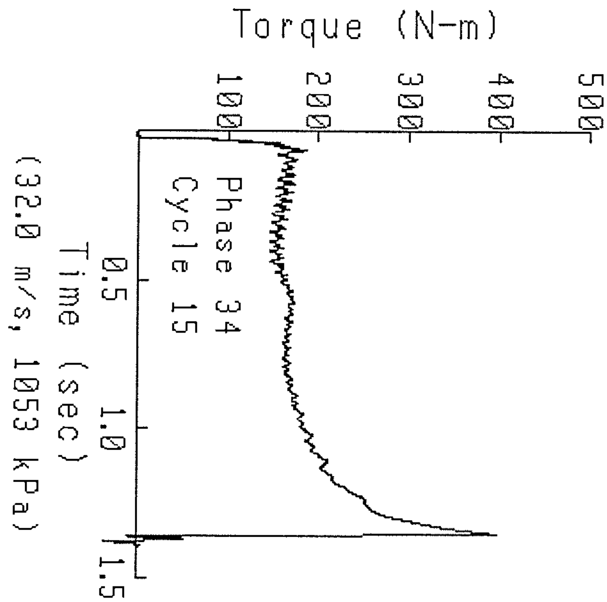

0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)

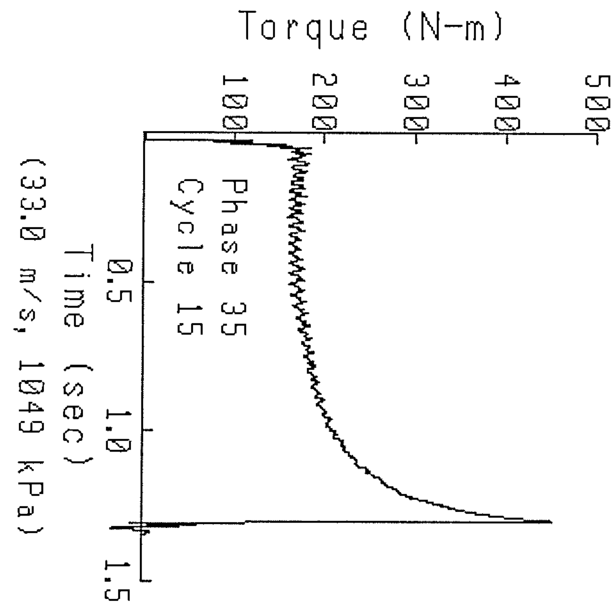

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)

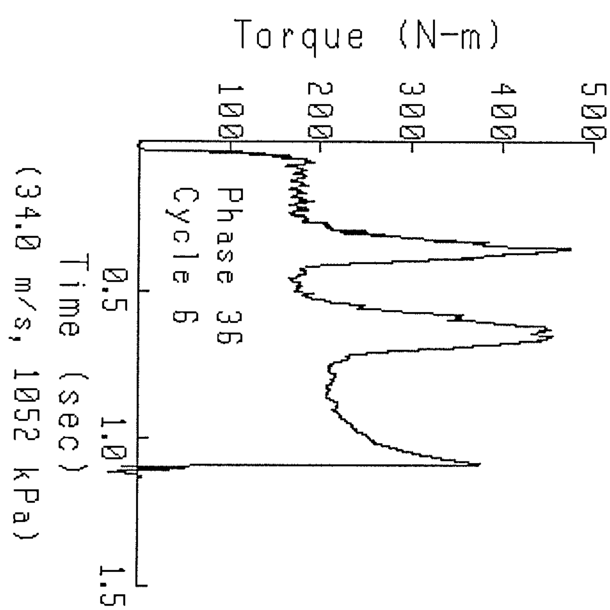

Torque (N-m)
100
200
300
400
500
Phase 31
Cycle 15
0.5
1.0
1.5
Time (sec)
(29.0 m/s, 1050 kPa)


Torque (N-m)
100
200
300
400
500
Phase 32
Cycle 15
0.5
1.0
1.5
Time (sec)
(30.0 m/s, 1051 kPa)


Torque (N-m)
100
200
300
400
500
Phase 33
Cycle 15
0.5
1.0
1.5
Time (sec)
(31.0 m/s, 1051 kPa)


Torque (N-m)
100
200
300
400
500
Phase 34
Cycle 15
0.5
1.0
1.5
Time (sec)
(32.0 m/s, 1053 kPa)

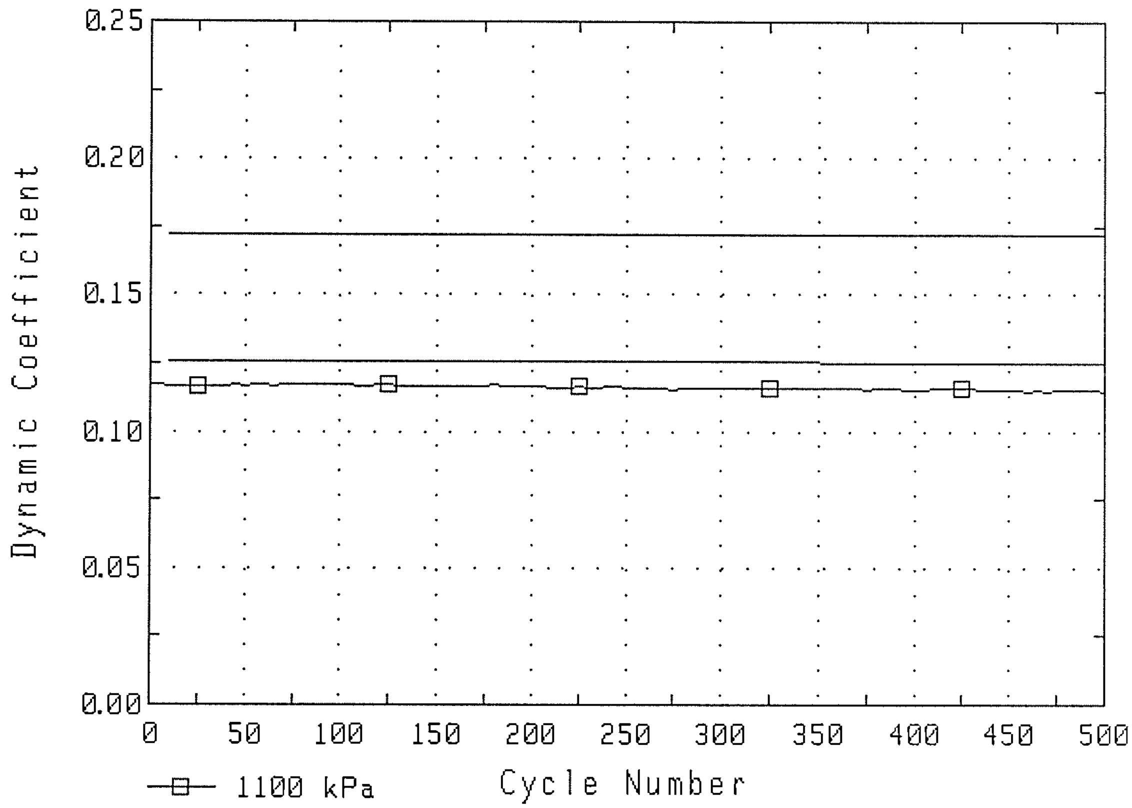

Torque (N-m)
100
200
300
400
500
Phase 35
Cycle 15
0.5
1.0
1.5
Time (sec)
(33.0 m/s, 1049 kPa)


Torque (N-m)
100
200
300
400
500
Phase 36
Cycle 6
0.5
1.0
1.5
Time (sec)
(34.0 m/s, 1052 kPa)

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO268869 / LO-268869

Test name:	A-163-J
Test date:	10/19/11
Test description:	J MACHINE LO268869
Oil type:	LO268869 / LO-268869
Viscosity:	N/A
Miscellaneous:	
Software version:	1.40
Run name & desc:	J0508337 - J MACHINE LO268869
Run date:	08/29/11
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J" MACHINE OIL TEST LO268869 / LO-268869
Sequence name:	SEQ1222
Remarks:	Use 1Y0711 Disc and 1Y0726 Plate
Number of cycles run:	1145
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 N-m-s^2
Disc name & desc:	1Y0711 - Wheel Brake Paper
Material:	Raybestos 7902-1 Paper
Groove pattern:	2 - 37 Multiple Parallel
Miscellaneous:	Use with 1Y0726 Steel Plate
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	06MR928188
Remarks:	WHEEL BRAKE PAPER
Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	06MR928188
Remarks:	0.24 SURFACE FINISH
Report limit name:	LIM1222 - Reference run: J0508195
Limit file generated:	08/04/10
Report format name:	REP1222 - WHEEL BRAKE PAPER

Test: A-163-J Run: J0508337 Started on 08/29/11 at 06:11



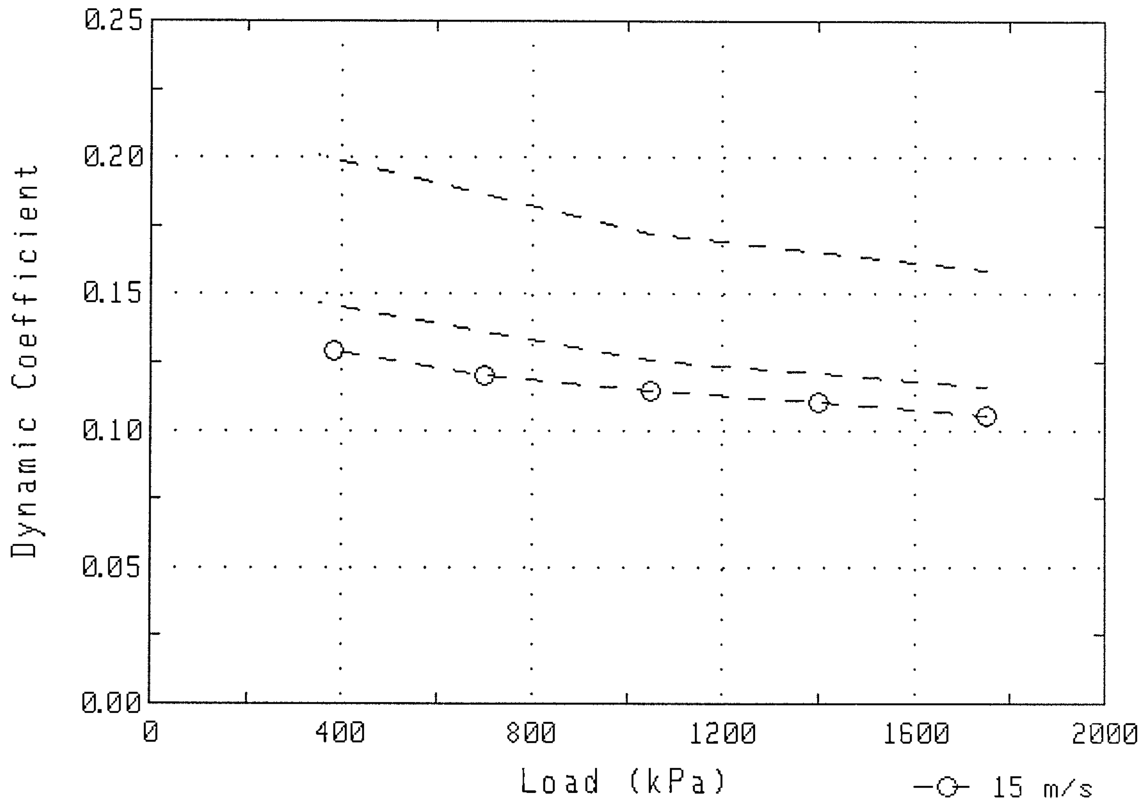
1Y0711 DISC
THICKNESS

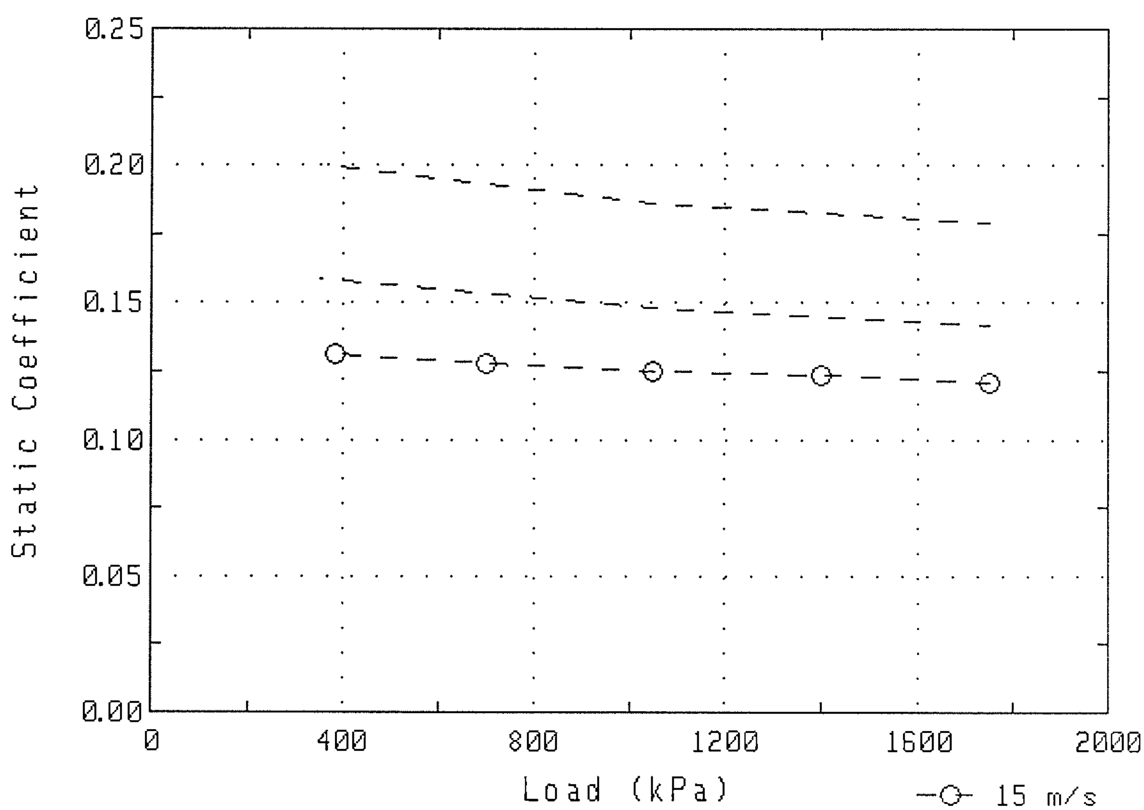
Loc	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
1	4.98	4.96	4.95	4.98	4.97	4.95
2	4.98	4.96	4.94	4.97	4.96	4.94
3	4.97	4.96	4.94	4.97	4.96	4.94
4	4.98	4.96	4.95	4.98	4.96	4.95
5	4.98	4.97	4.96	4.98	4.98	4.96
6	4.99	4.98	4.96	4.99	4.98	4.96
Avg	4.98	4.97	4.95	4.98	4.97	4.95

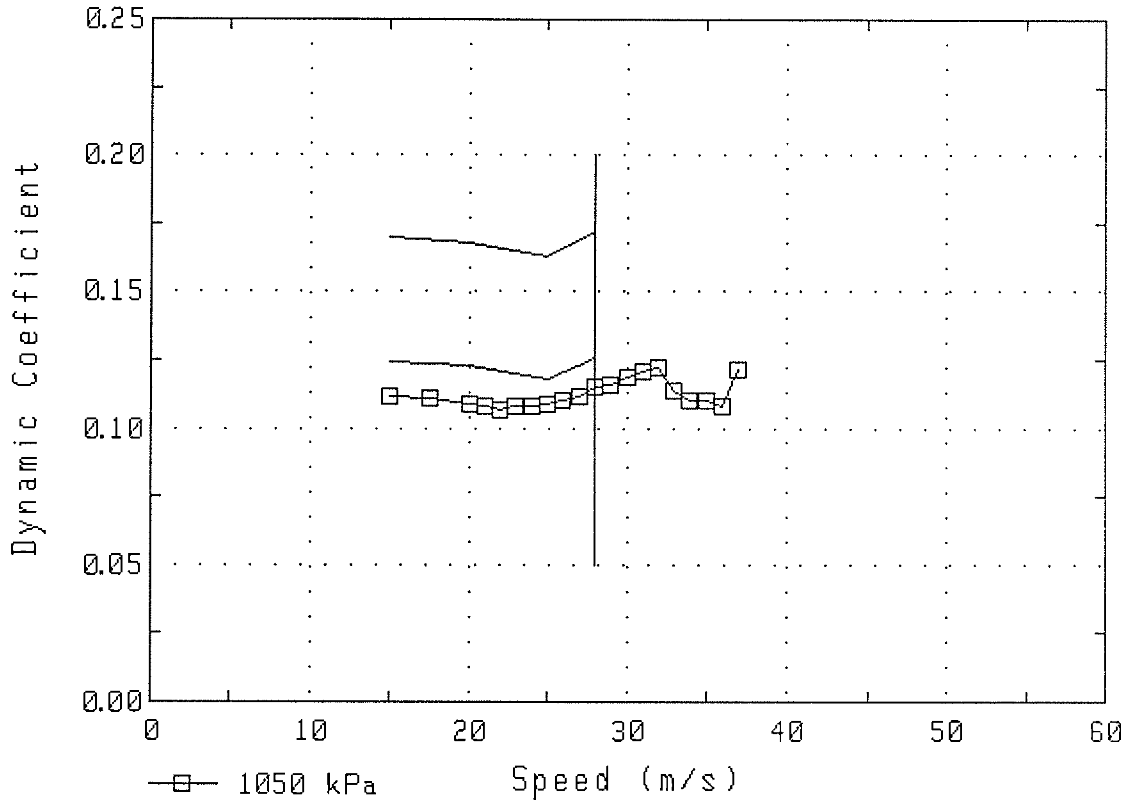
Compression set average wear: 0.013
M2 - M3 average Wear: 0.017

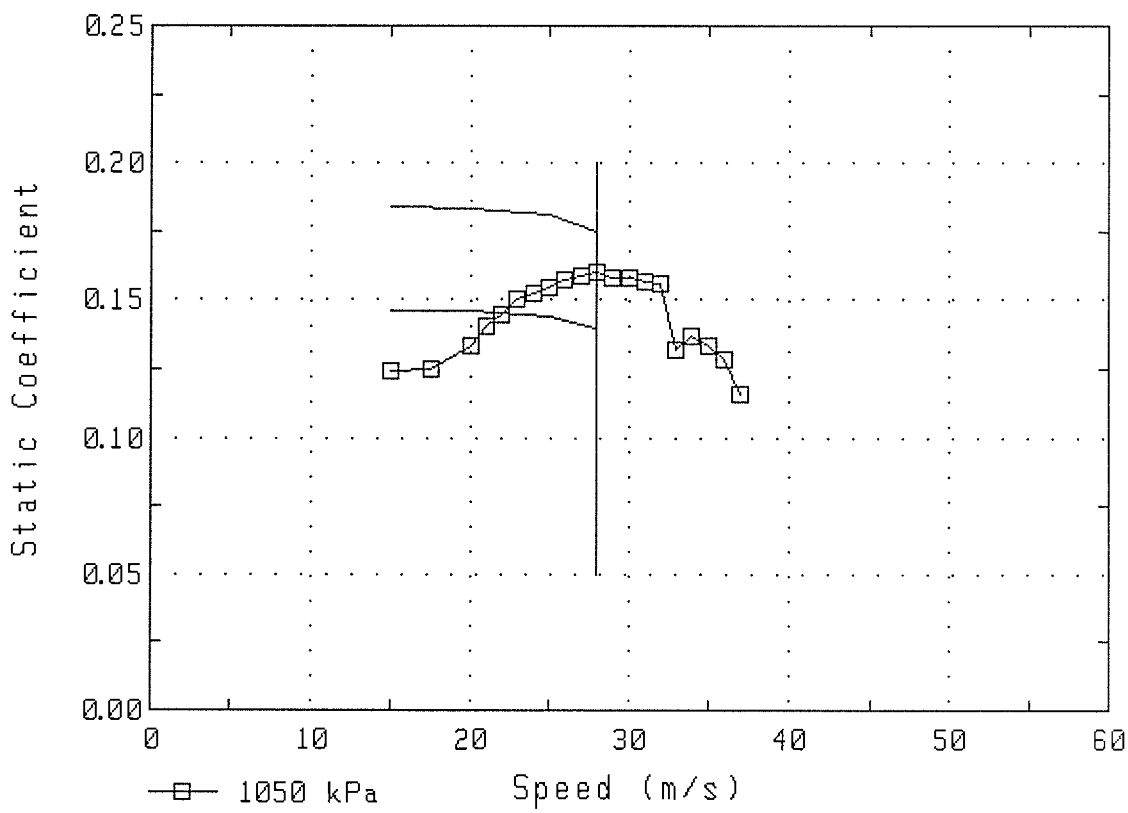
Total Wear (all measurements in mm): 0.029

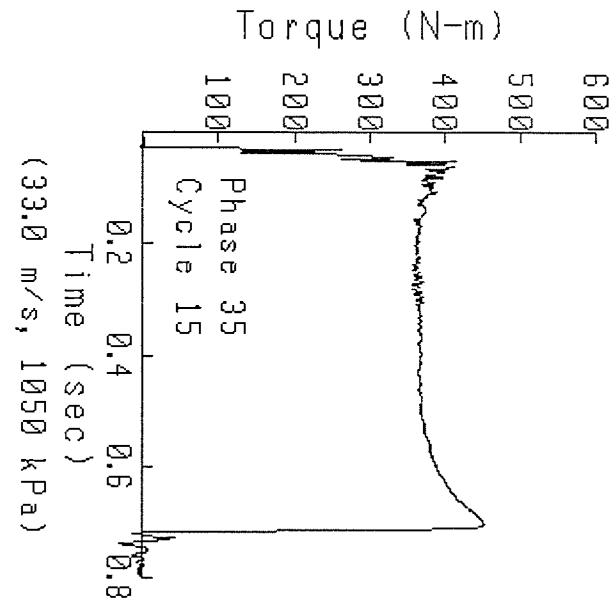
Test: A-163-J Run: J0508337 Started on 08/29/11 at 06:11

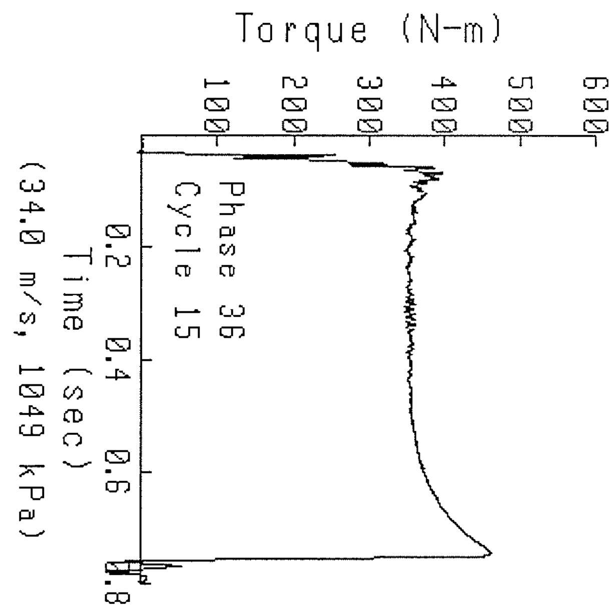


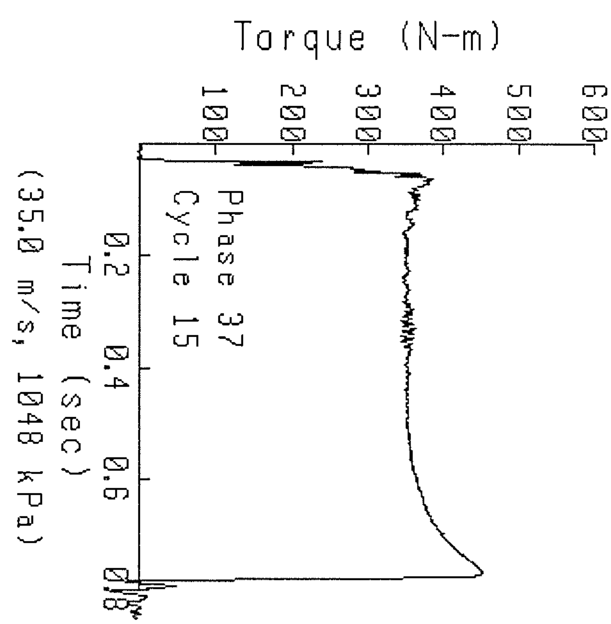


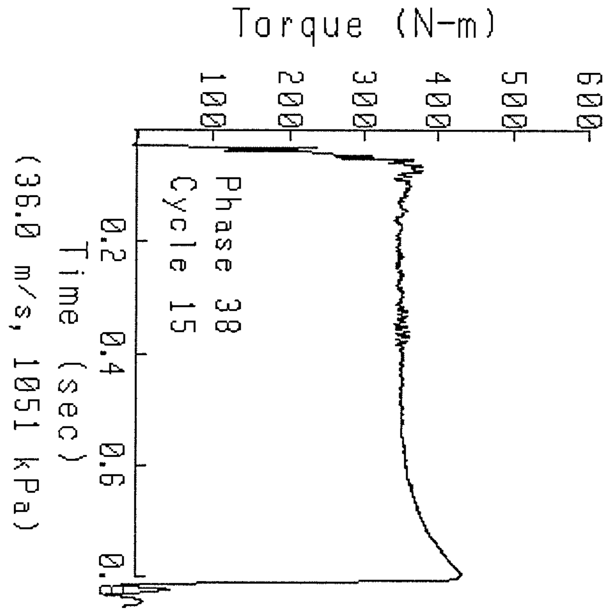

0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)

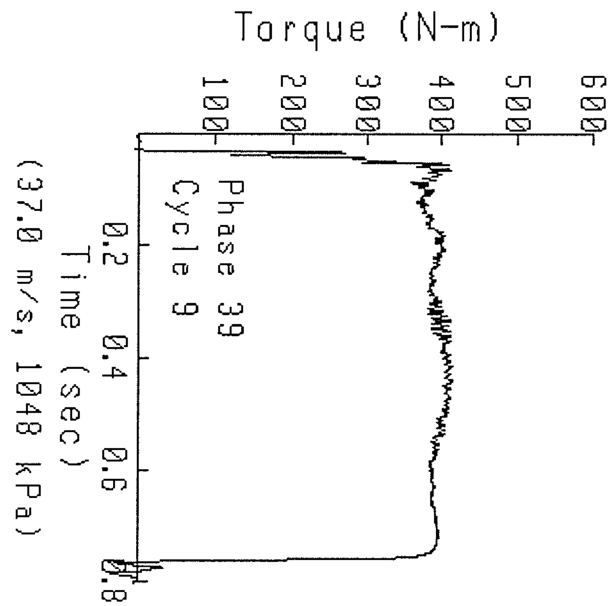

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)

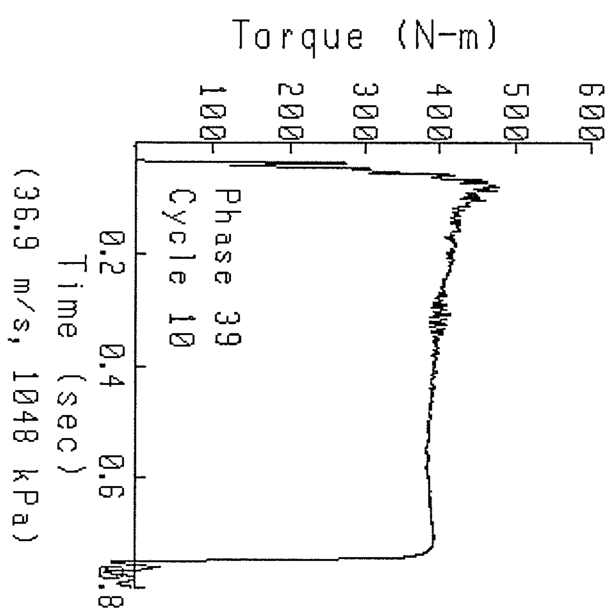

Torque (N-m)
100 200 300 400 500 600
Phase 35
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(33.0 m/s, 1050 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 36
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(34.0 m/s, 1049 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 37
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(35.0 m/s, 1048 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 38
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(36.0 m/s, 1051 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 39
Cycle 9
0.2 0.4 0.6 0.8
Time (sec)
(37.0 m/s, 1048 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 39
Cycle 10
0.2 0.4 0.6 0.8
Time (sec)
(36.9 m/s, 1048 kPa)

APPENDIX – E2

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

LO271510

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Conducted for

ARMY LAB

Oil Code:
LO271510

Test Number:
VC70-A-164-J

October 21, 2011

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: ARMY LAB

Test start date: 10/20/2011
End of test date: 10/21/2011
Oil Code: LO271510

Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:		P		F			
Dynamic Coefficient Vs. Load:		P		F			
Dynamic Coefficient Vs. Speed:		P		F			
Energy Limit:		P		P			
Static Coefficient Vs. Load:		P		P			
Static Coefficient Vs. Speed:		P		P			
Energy Limit:		P		P			
Total Wear:		0.006		0.029			
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand. The results are compared to TO-4 testing limits. 2009 Batch parts were used for this sequence.

F = Fail
P = Pass
N/A = Not Applicable

Test name:	A-164-J
Test date:	10/20/11
Test description:	J MACHINE LO271510
Oil type:	LO271510 / LO-271510
Viscosity:	N/A
Miscellaneous:	
Software version:	1.40

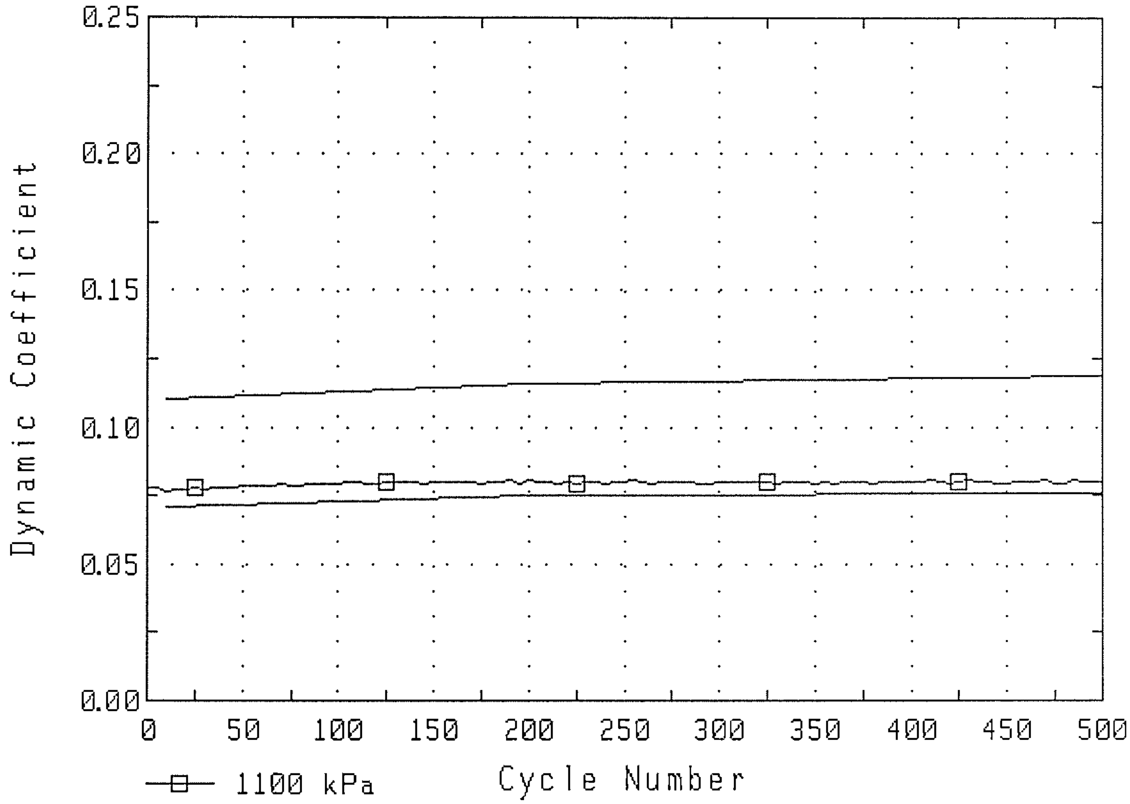
Run name & desc:	J0508338 - J MACHINE LO271510
Run date:	08/30/11
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J" MACHINE OIL TEST LO271510 / LO-271510
Sequence name:	SEQ1220
Remarks:	Use 1Y0709 Disc and 8E4095 Plate
Number of cycles run:	1140

Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 N-m-s^2

Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	007080C800012
Remarks:	SINTERED BRONZE

Plate name & desc:	8E4095 - Steel Plate
Surface:	0.70 to 1.00 micron Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	007080C800012
Remarks:	0.90 SURFACE FINISH

Report limit name:	LIM1220 - Reference run: J0508081
Limit file generated:	10/19/11
Report format name:	REP1220 - SINTERED BRONZE

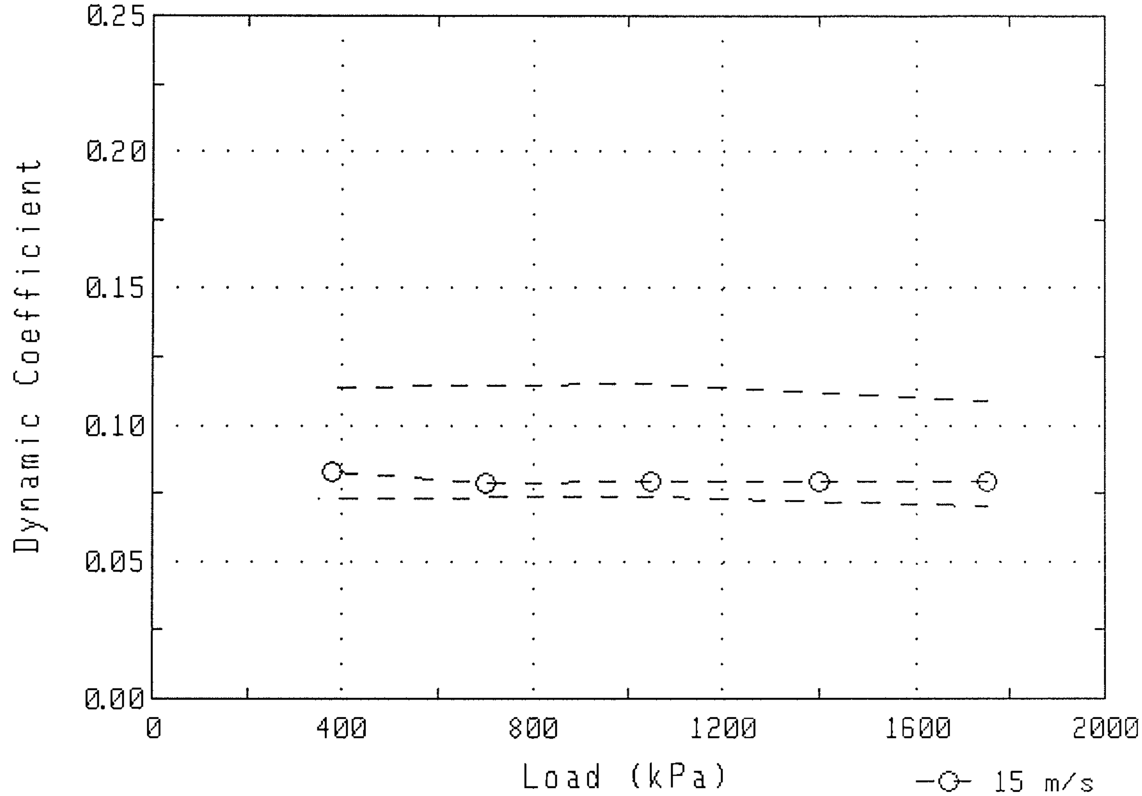


1Y0709 DISC
THICKNESS

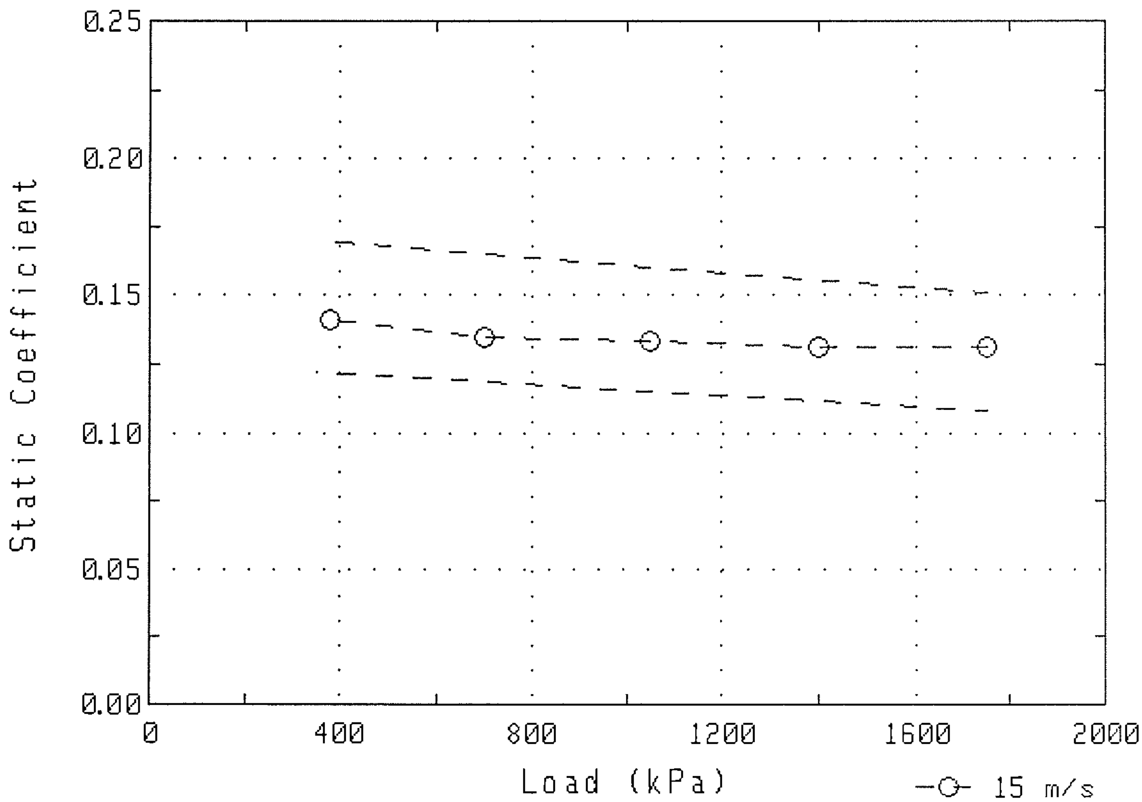
Loc	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
1	4.92	4.92	4.92	4.92	4.92	4.92
2	4.95	4.94	4.94	4.94	4.93	4.93
3	4.93	4.93	4.93	4.93	4.93	4.93
4	4.93	4.92	4.92	4.93	4.92	4.92
5	4.93	4.92	4.92	4.92	4.92	4.92
6	4.93	4.92	4.92	4.93	4.92	4.92
Avg	4.93	4.93	4.93	4.93	4.92	4.92

Compression set average wear: 0.006
M2 - M3 average Wear: 0.000

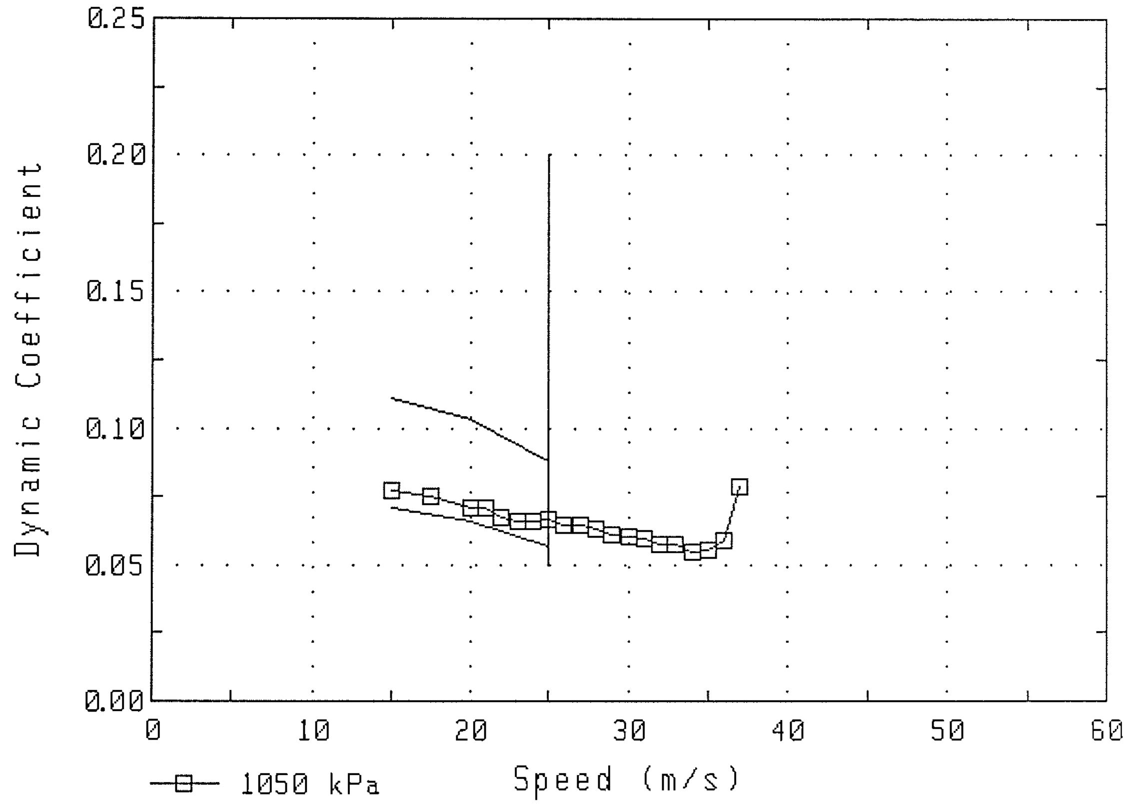
Total Wear (all measurements in mm): 0.006

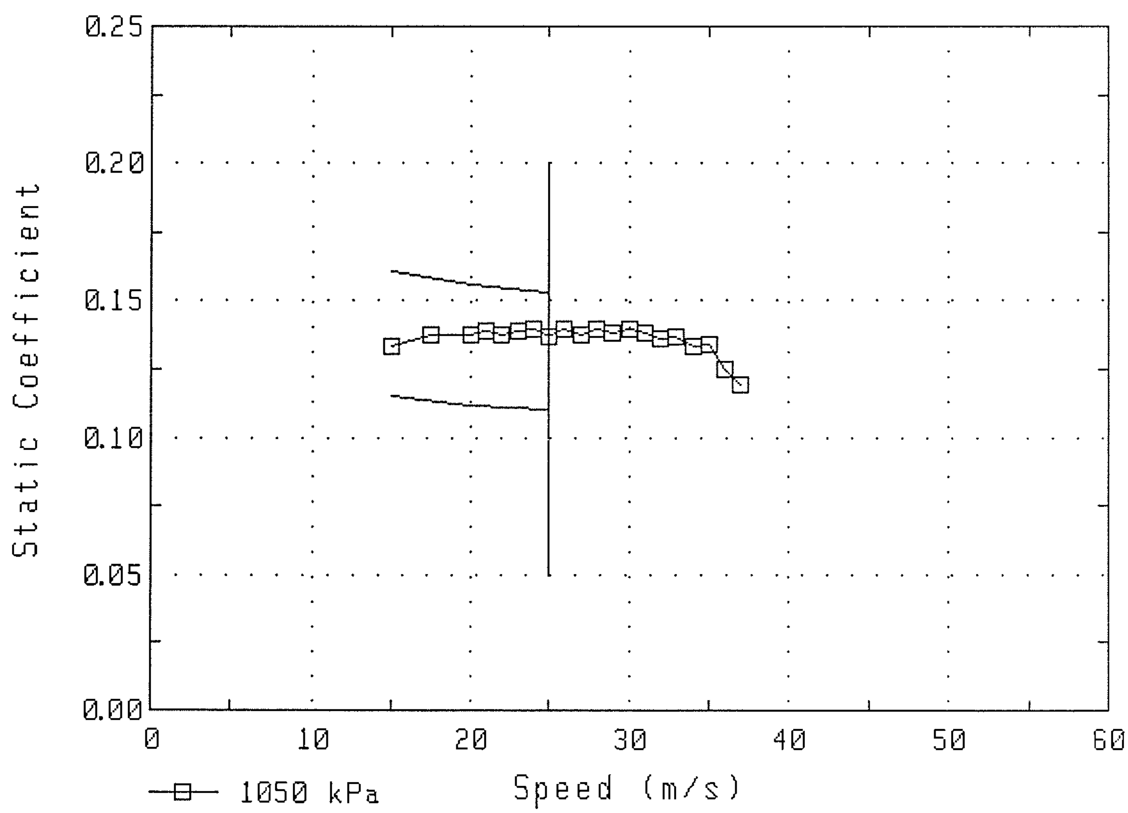


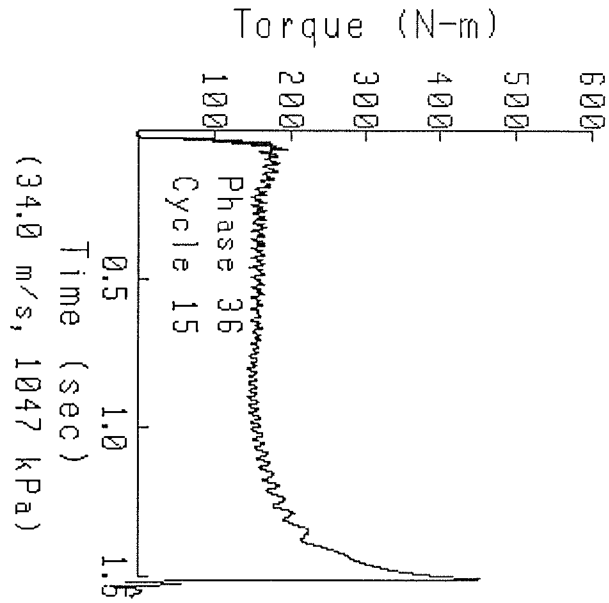
0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

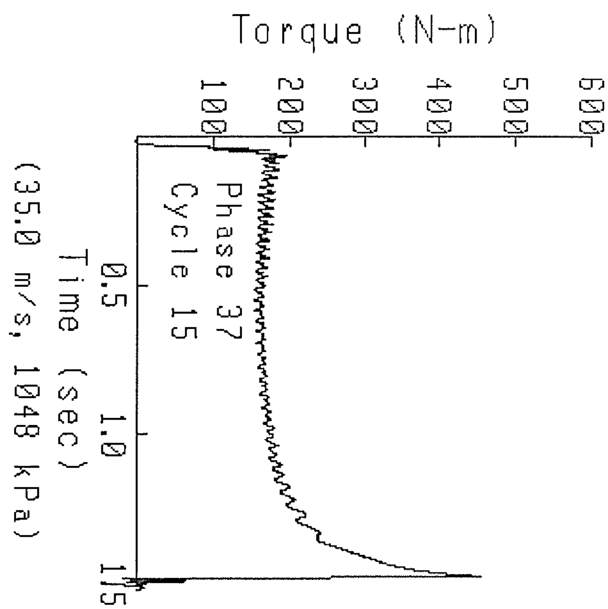


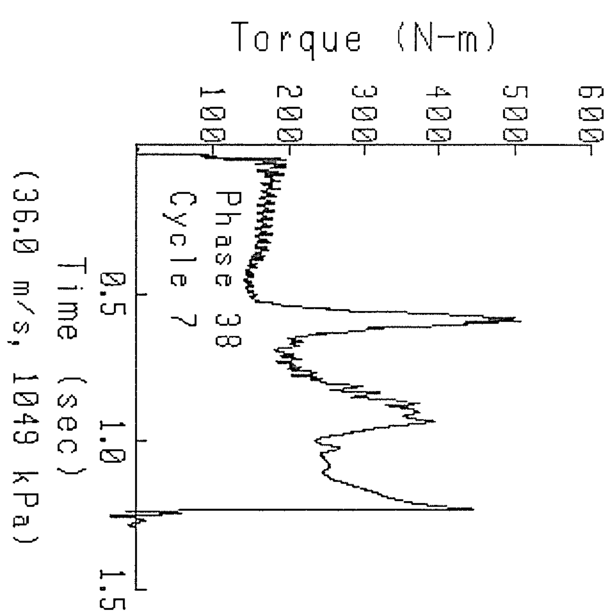
0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

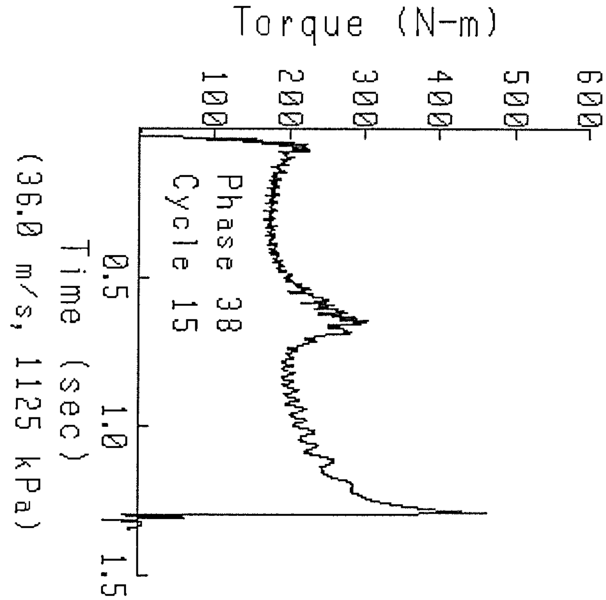

0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

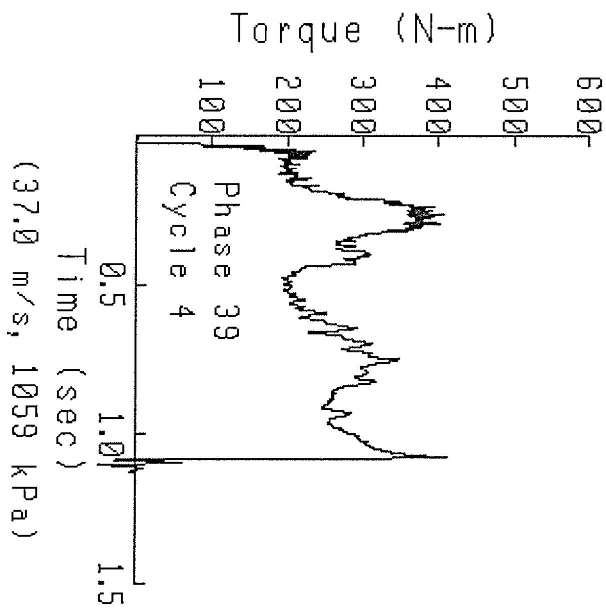

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

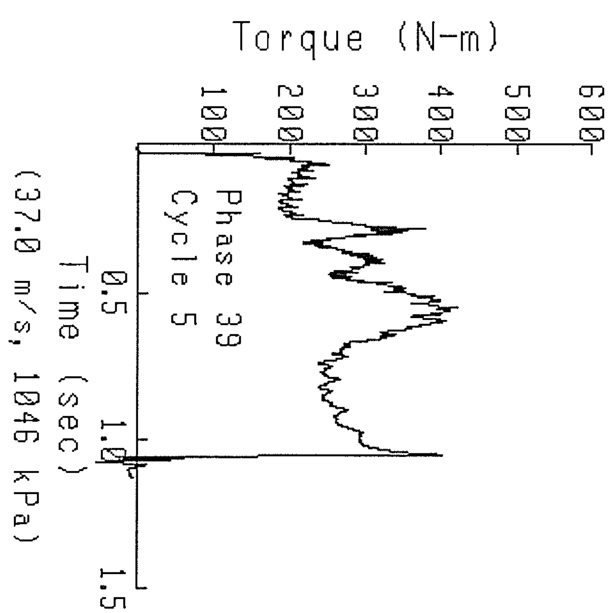

Torque (N-m)
100 200 300 400 500 600
Phase 36
Cycle 15
0.5 1.0 1.5
Time (sec)
(34.0 m/s, 1047 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 37
Cycle 15
0.5 1.0 1.5
Time (sec)
(35.0 m/s, 1048 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 38
Cycle 7
0.5 1.0 1.5
Time (sec)
(36.0 m/s, 1049 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 38
Cycle 15
0.5 1.0 1.5
Time (sec)
(36.0 m/s, 1125 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 39
Cycle 4
0.5 1.0 1.5
Time (sec)
(37.0 m/s, 1059 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 39
Cycle 5
0.5 1.0 1.5
Time (sec)
(37.0 m/s, 1046 kPa)

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO271510 / LO-271510

Test name:	A-164-J
Test date:	10/21/11
Test description:	J MACHINE LO271510
Oil type:	LO271510 / LO-271510
Viscosity:	N/A
Miscellaneous:	
Software version:	1.40

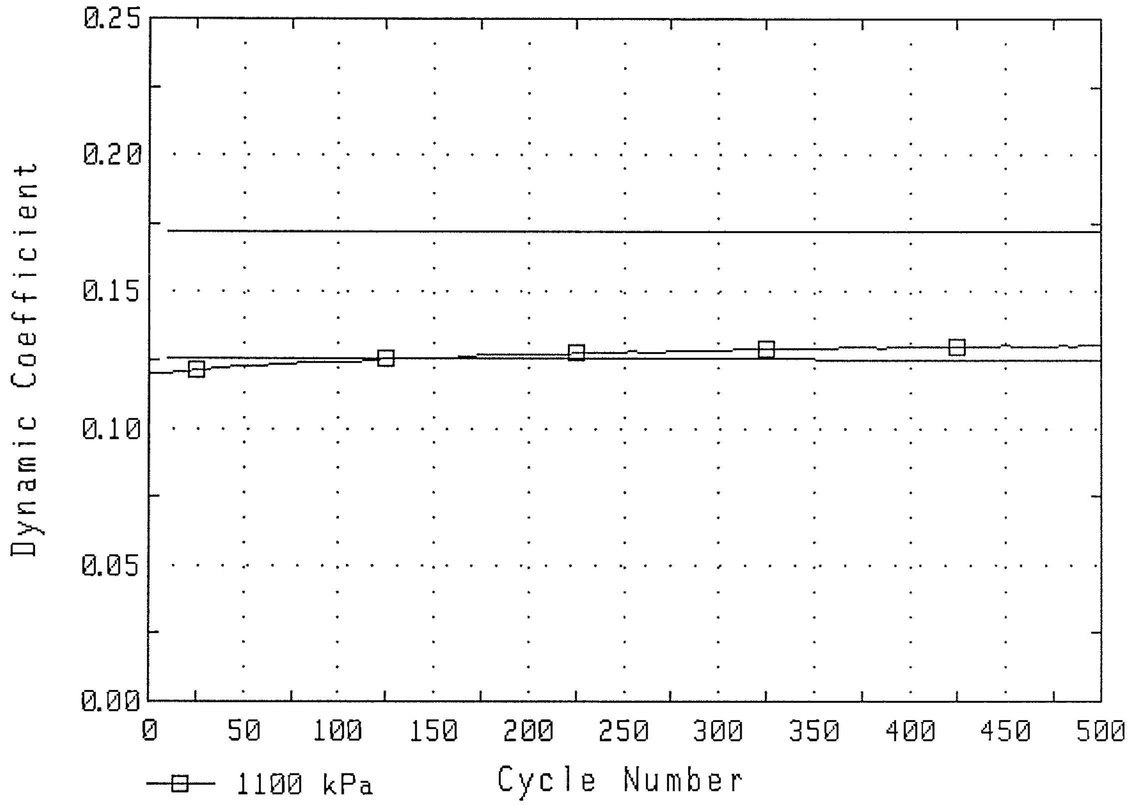
Run name & desc:	J0508339 - J MACHINE LO271510
Run date:	08/31/11
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J" MACHINE OIL TEST LO271510 / LO-271510
Sequence name:	SEQ1222
Remarks:	Use 1Y0711 Disc and 1Y0726 Plate
Number of cycles run:	1132

Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 N-m-s^2

Disc name & desc:	1Y0711 - Wheel Brake Paper
Material:	Raybestos 7902-1 Paper
Groove pattern:	2 - 37 Multiple Parallel
Miscellaneous:	Use with 1Y0726 Steel Plate
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	06MR928188
Remarks:	WHEEL BRAKE PAPER

Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	06MR928188
Remarks:	0.32 SURFACE FINSH

Report limit name:	LIM1222 - Reference run: J0508195
Limit file generated:	08/04/10
Report format name:	REP1222 - WHEEL BRAKE PAPER



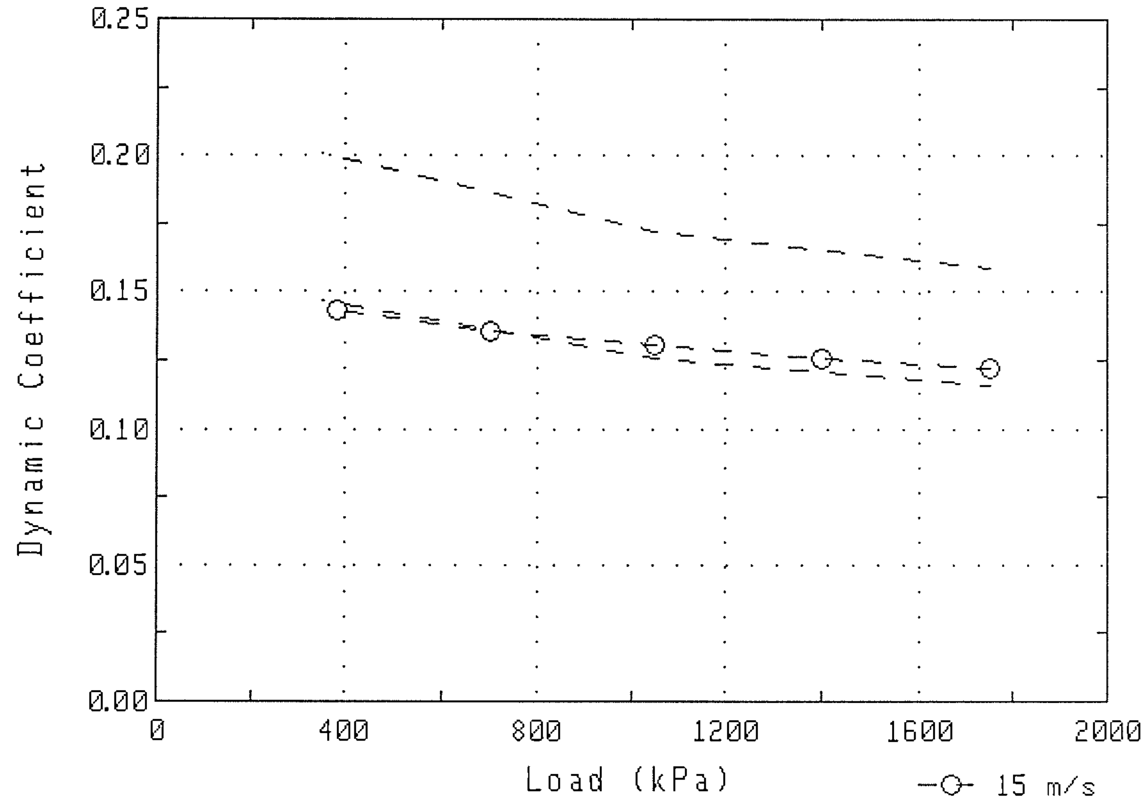
1Y0711 DISC
THICKNESS

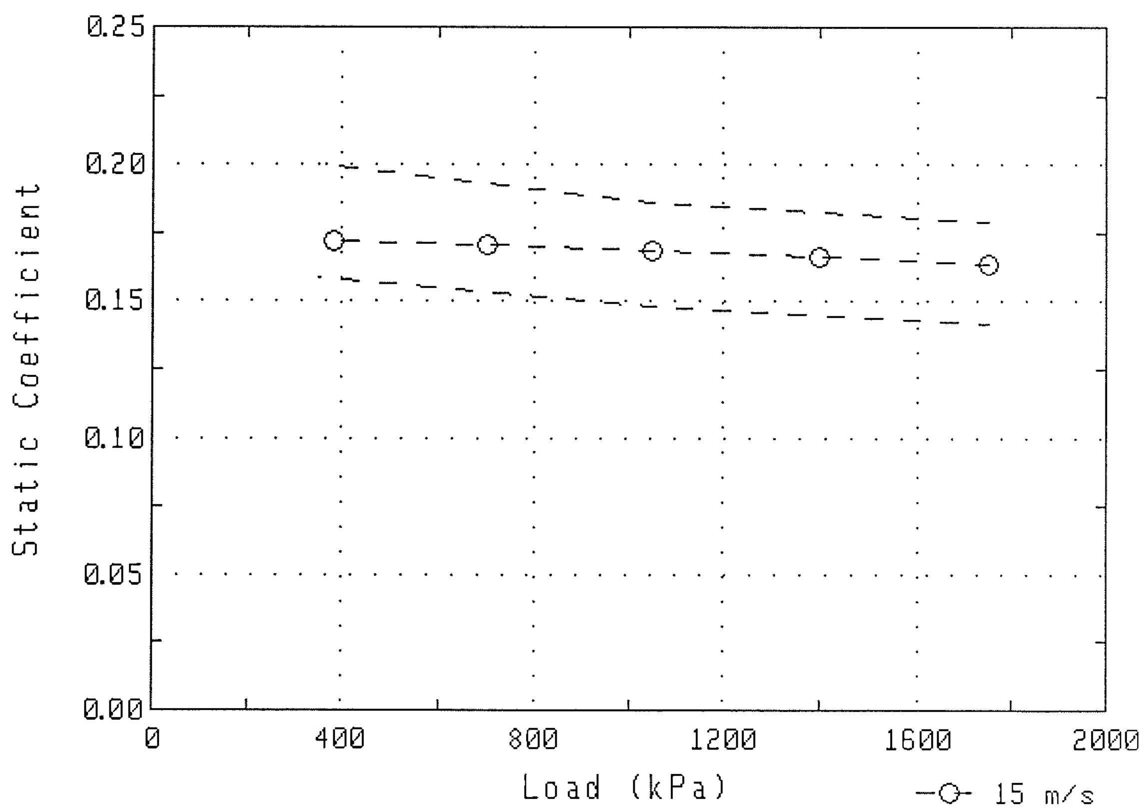
Loc	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
1	4.92	4.89	4.88	4.91	4.89	4.88
2	4.89	4.86	4.86	4.88	4.86	4.85
3	4.89	4.86	4.86	4.89	4.87	4.86
4	4.90	4.87	4.87	4.90	4.87	4.87
5	4.89	4.87	4.87	4.89	4.87	4.87
6	4.91	4.88	4.88	4.91	4.88	4.88
Avg	4.90	4.87	4.87	4.90	4.87	4.87

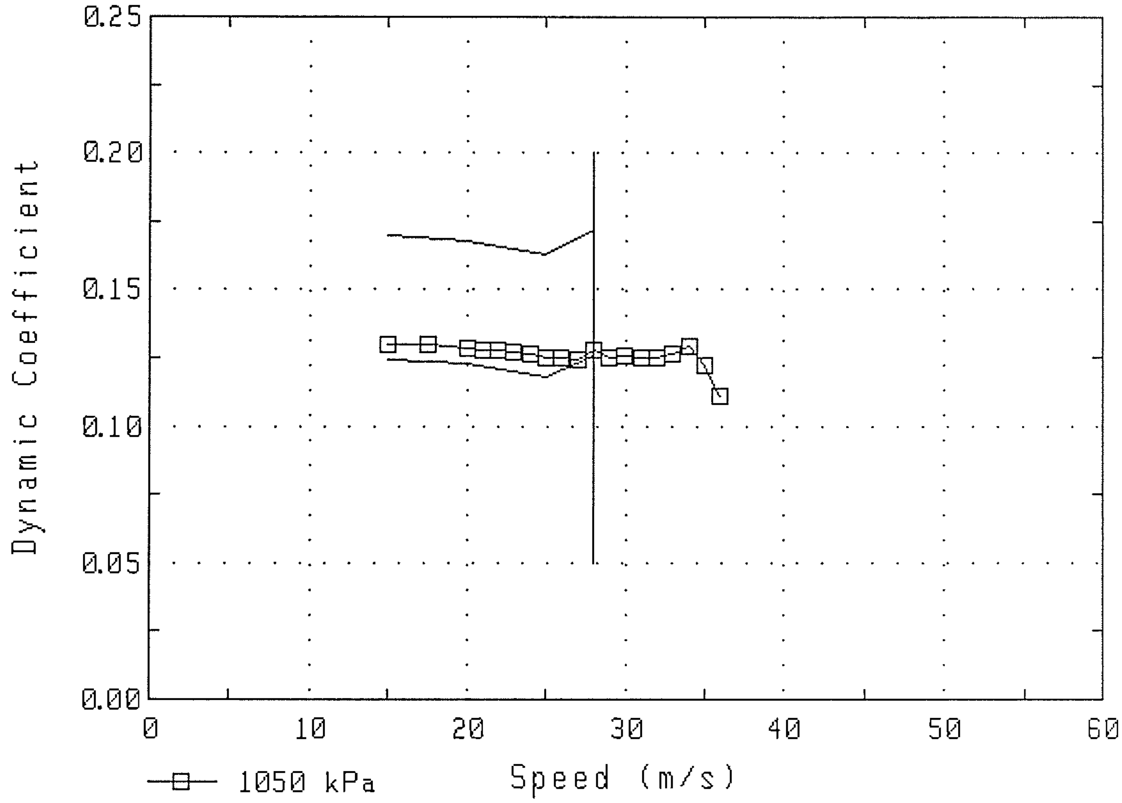
Compression set average wear: 0.026
M2 - M3 average Wear: 0.003

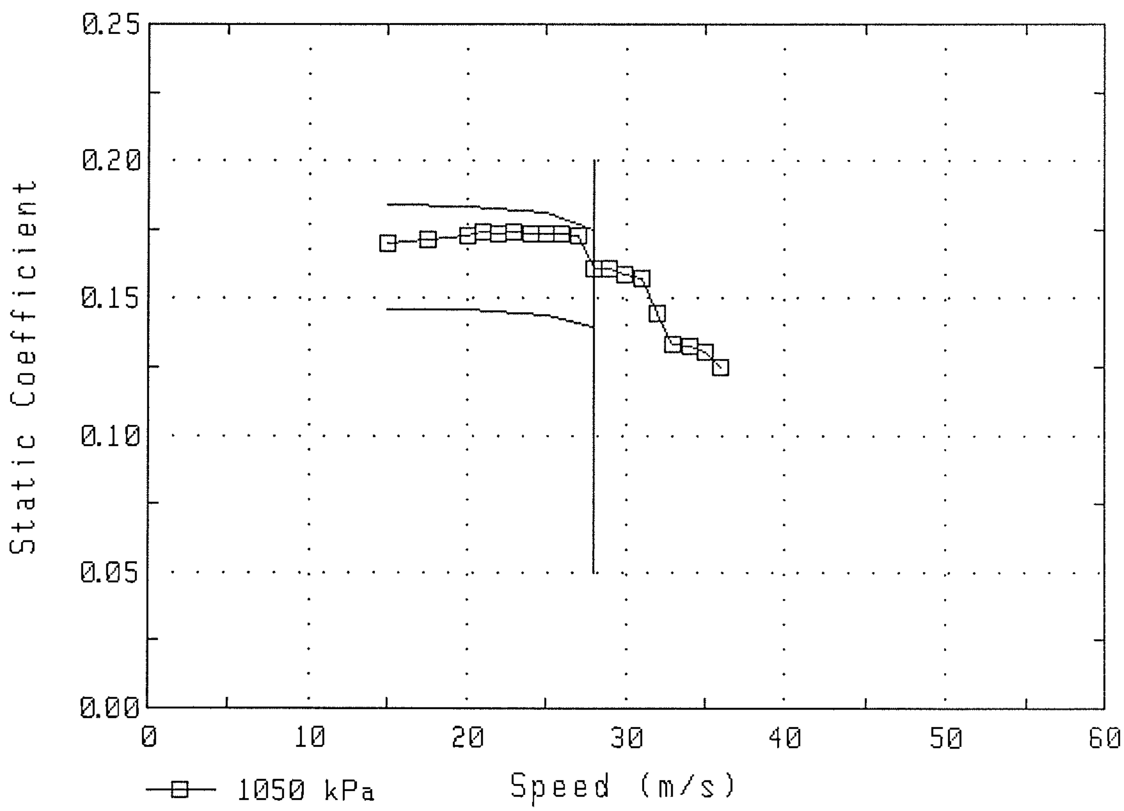
Total Wear (all measurements in mm): 0.029

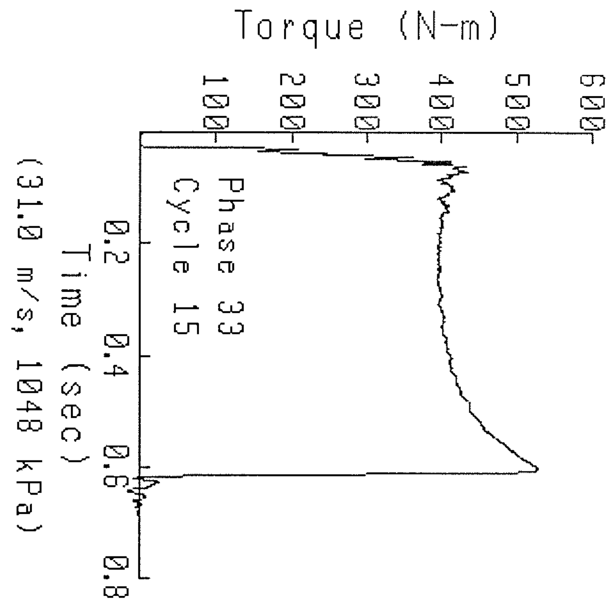
Test: A-164-J Run: J0508339 Started on 08/31/11 at 07:25

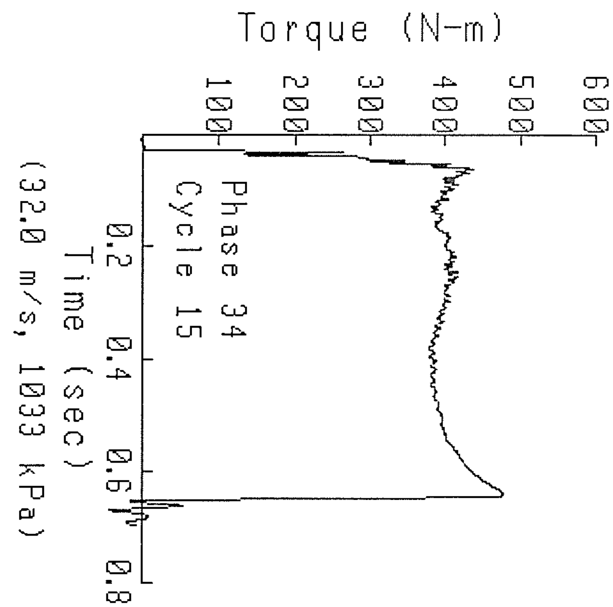


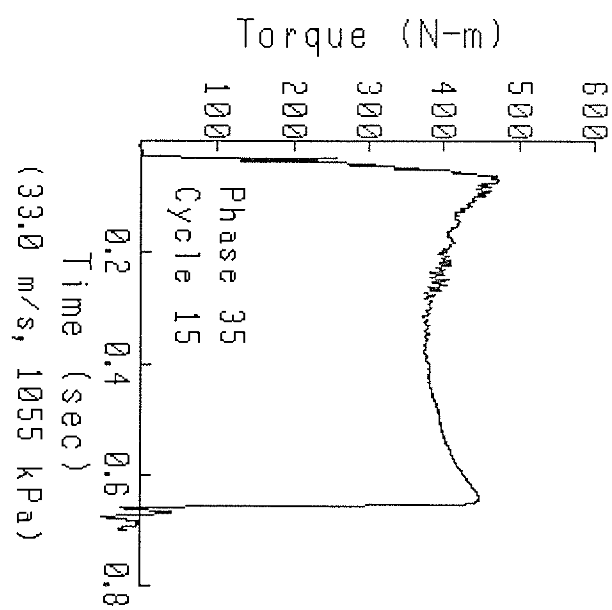


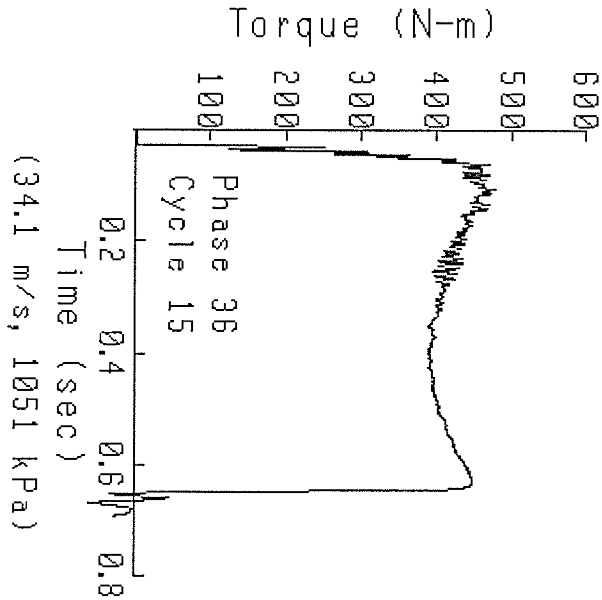

0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)

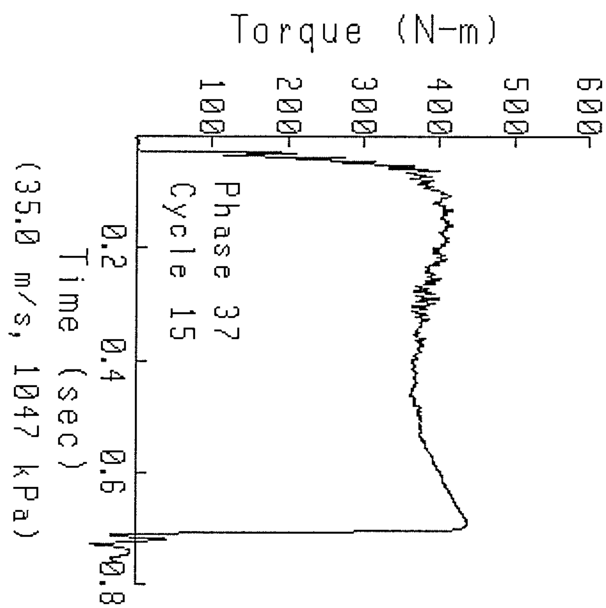

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)

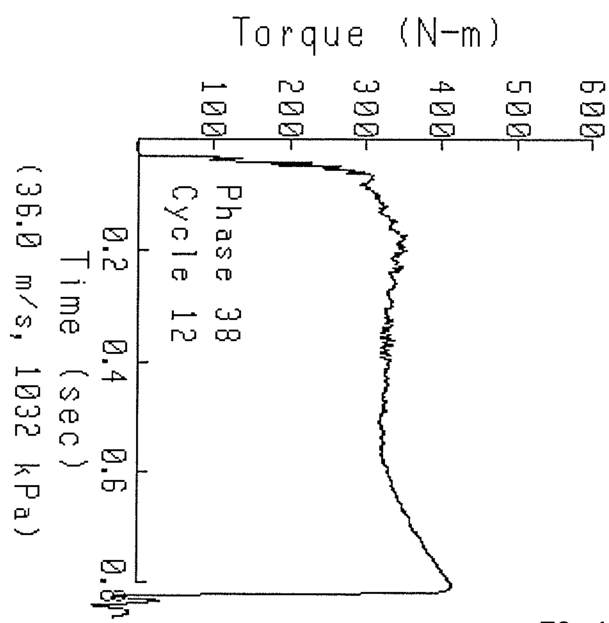

Torque (N-m)
100 200 300 400 500 600
Phase 33
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(31.0 m/s, 1048 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 34
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(32.0 m/s, 1033 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 35
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(33.0 m/s, 1055 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 36
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(34.1 m/s, 1051 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 37
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(35.0 m/s, 1047 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 38
Cycle 12
0.2 0.4 0.6 0.8
Time (sec)
(36.0 m/s, 1032 kPa)

APPENDIX – F1

JOHN DEERE JDQ-96
PERFORMED USING 1400 SERIES AXLE
LO268869

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

John Deere JDQ-96
Performed using 1400 Series Axle

Conducted for

U.S. Army TARDEC Fuels and Lubricants Research Facility

LO268869

Test Number
11843

November 23, 2011

Submitted by:

Brian Decker
Engineer
Specialty & Driveline Fluid Evaluations

John Deere JDQ-96 Performed using 1400 Series Axle

General Information

Oil Code: LO268869	E.O.T. Date: November 23, 2011

Purpose

The purpose of this test was to evaluate the anti-chatter properties of this oil on the brakes of a 1400 series John Deere Inboard Planetary Axle.

Test Procedure

The test was performed as specified by John Deere Product Engineering. The only changes made to the Deere procedure were those necessary to compensate for a different spiral bevel gear ratio. This procedure is proprietary to Deere and Company.

Data Interpretation

The capacity for each engagement is the average torque during the middle of the engagement. The torque variation is the greatest difference between the maximum and minimum torque recorded during any 0.2-second portion of the engagement. The SwRI variation is the sum of all differences between the maximum torque and minimum torque for each engagement. It is obtained by summing all torque variations of each 0.2-second time block of all engagements.

Test Number

The run number listed on this report is a random number and is not sequential. Only SwRI® can link this run number to JDQ-96, LO268869, November 23, 2011.

John Deere JDQ-96 Performed using 1400 Series Axle

Results

Oil Code: LO268869	**E.O.T. Date:** November 23, 2011

The candidate results can be compared to the baseline reference average. Pass or fail decisions are only made by John Deere Product Engineering. The current reference baseline average is the average of the five most recent tests.

Current Reference Baseline Average (N · m)					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	330,753	340,749	339,241	341,212	1,351,955
Torque Variation	171,228	148,851	144,908	139,005	603,993

Results From Test Candidate LO268869					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	335,125	N/A	N/A	N/A	335,125
Torque Variation	206,202	N/A	N/A	N/A	206,202

Table 1 of the Appendix contains chatter test results from 1,000. Table 2 contains results of the five current baseline reference tests. Table 3 contains the history of tests conducted on reference oil and a graphic presentation of 1000-cycle reference results on LO268869.

Figures 1 and 2 are graphic presentations of candidate oil performance compared to baseline reference data.

John Deere JDQ-96 Performed using 1400 Series Axle

Oil Code: LO268869	**E.O.T. Date:** November 23, 2011

Appendix

1. Table 1 – Durability results 1,000 cycles Candidate Oil
2. Table 2 – Reference Data Compared to Candidate Data
3. Table 3 – History of tests conducted on reference oil & graphic presentation of 1000 cycle reference results & Candidate
4. Figure 1 & Figure 2 - Torque Variation & Relative Capacity Chart

TABLE 1: JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES
Electrically Powered Test Stand

Sponsor Oil Code LO268869 Date November 23, 2011

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	4335	2220	21	4201	1427	47	4067	1413	59	4228	1241	68
10	3831	4369	2423	21	4192	1811	47	4043	1645	59	4199	1570	68
15	3831	4364	2865	21	4140	2316	46	4026	2242	58	4127	2257	67
20	3831	4312	2864	21	4117	2807	47	3977	2826	58	4104	2573	67
25	3831	4240	3226	22	4059	2858	47	3930	2818	59	4057	2842	68
30	3831	4178	2967	22	4001	2800	48	3875	2618	59	4003	2718	68
35	3831	4123	2750	23	3950	2513	48	3829	2665	59	3960	2701	68
40	3831	4077	2731	24	3896	2575	48	3784	2533	59	3919	2631	68
45	3831	4023	2741	25	3852	2587	48	3736	2507	59	3859	2375	68
50	3831	3959	2557	27	3810	2427	48	3697	2625	59	3833	2557	68
55	3831	3909	2551	28	3773	2300	49	3661	2480	60	3795	2309	69
60	3831	3864	2441	29	3732	2367	50	3622	2411	61	3768	2595	70
15	1532	1584	2400	30	1621	2369	50	1625	2296	61	1606	2331	70
15	2300	2477	2452	30	2465	2525	49	2483	2402	60	2452	2485	69
15	3065	3324	2718	30	3312	2501	45	3348	2531	60	3289	2435	69
15	3831	4211	2691	30	4150	2748	45	4173	2524	60	4151	2595	68
15	4598	5033	2872	30	4979	2680	46	4808	2604	60	4937	2520	68
15	5364	5862	3257	30	5767	3184	46	5717	2913	59	5676	2799	68
15	6130	6120	3467	30	6080	2995	46	6538	3211	59	6461	3218	68
15	7050	7614	3027	31	7482	3180	46	7048	3106	59	7157	2894	67

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	85,978	55,218	896,035
49	83,577	50,970	822,720
60	81,987	50,368	795,669
71	83,584	49,645	784,552
TOTAL	335,125	206,202	3,298,976

TABLE 2: JDQ-96 Electric Initial Test Stand REFERENCE DATA

Candidate Oil Code : LO268869 EOT Date: November 23, 2011
Reference Oil Code : 69X31111M

	Cycles	Relative Capacity	Torque Variation	SwRI Variation	Average Facing Thickness (millimeters)
First Reference Run					
11279	1,000	329,975	160,449	2,530,213	7.45
	10,000	336,719	115,287	1,647,685	7.23
	20,000	334,984	119,314	1,755,276	7.03
	30,000	335,508	119,149	1,592,586	6.78
	Total	1,337,186	514,198	7,525,760	
Second Reference Run					
11852	1,000	327,258	172,283	2,624,608	7.42
	10,000	336,696	208,440	2,732,636	7.24
	20,000	339,033	152,391	2,143,494	7.08
	30,000	333,213	147,746	2,127,478	6.94
	Total	1,336,201	680,859	9,628,216	
Third Reference Run					
11663	1,000	325,464	179,529	2,696,409	7.43
	10,000	340,089	146,169	2,145,968	7.23
	20,000	330,568	145,948	2,016,724	7.07
	30,000	332,713	148,011	2,001,514	6.88
	Total	1,328,834	619,656	8,860,614	
Fourth Reference Run					
11922	1,000	325,990	179,251	2,596,844	7.46
	10,000	334,464	156,902	2,185,176	7.31
	20,000	333,886	183,892	2,437,145	7.18
	30,000	339,695	147,072	2,033,787	7.07
	Total	1,334,036	667,118	9,252,951	
Fifth Reference Run					
11175	1,000	345,076	164,630	2,569,506	7.46
	10,000	355,779	117,458	1,636,195	7.26
	20,000	357,736	122,993	1,721,073	7.09
	30,000	364,928	133,050	1,799,847	6.84
	Total	1,423,519	538,132	7,726,620	
Candidate oil					
LO268869		335,125	206,202	3,298,976	

Table 3: History of 1000 cycle reference tests

Candidate Oil Code: LO268869 EOT Date: November 23, 2011

Oil Code	Comments	Torque Variation 1000 cycles
69X31111M	new piston and backing plate	160,449
69X31111M	new piston and backing plate	172,283
69X31111M	new piston and backing plate	179,529
69X31111M	new piston and backing plate	179,251
69X31111M	new piston and backing plate	164,630
69X31111M	new piston and backing plate	194,668
69X31111M	new piston and backing plate	183,301
LO268869	new piston and backing plate	206,202

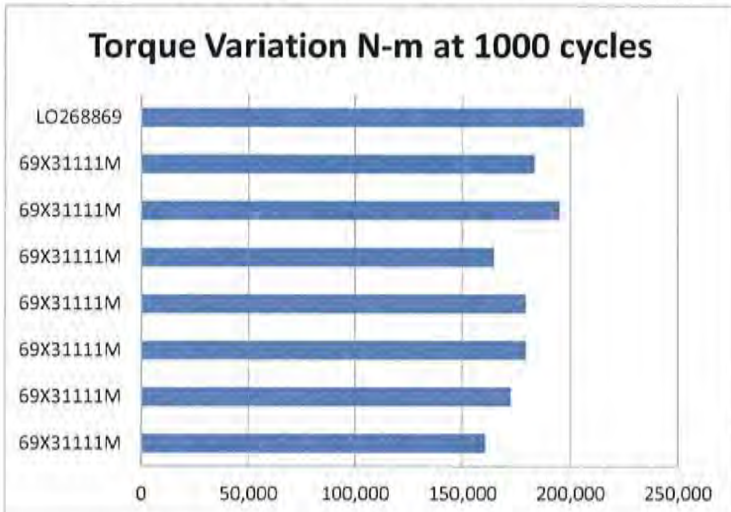


Figure 1

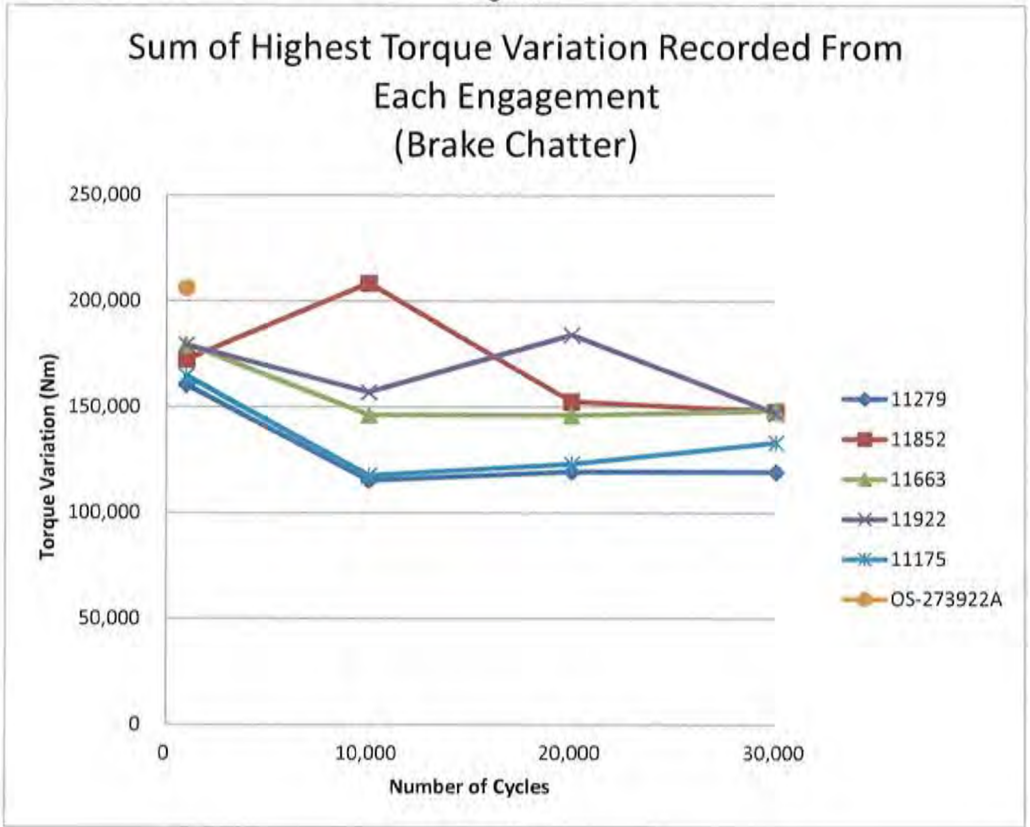
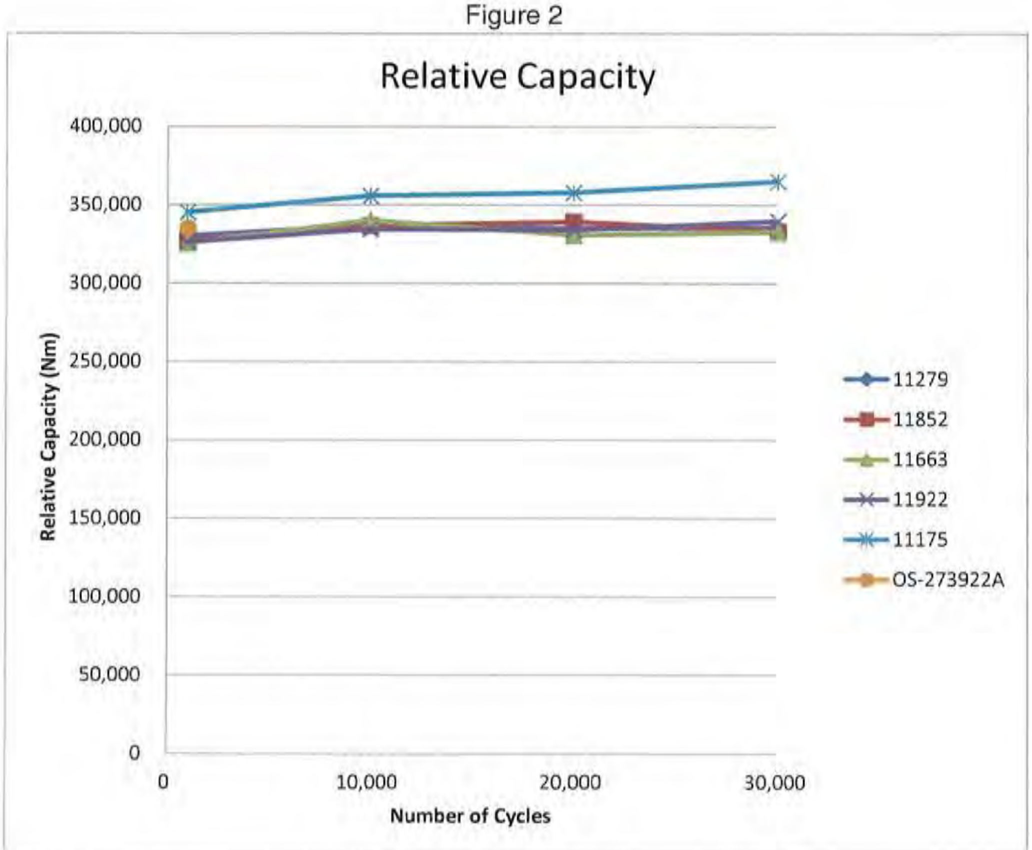


Figure 2



APPENDIX – F2

JOHN DEERE JDQ-96
PERFORMED USING 1400 SERIES AXLE

LO271510

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

John Deere JDQ-96
Performed using 1400 Series Axle

Conducted for

U.S. Army TARDEC Fuels and Lubricants Research Facility

LO271510

Test Number
11114

December 1, 2011

Submitted by:

Brian Decker
Engineer
Specialty & Driveline Fluid Evaluations

John Deere JDQ-96 Performed using 1400 Series Axle

General Information

Oil Code: LO271510	E.O.T. Date: December 1, 2011

Purpose

The purpose of this test was to evaluate the anti-chatter properties of this oil on the brakes of a 1400 series John Deere Inboard Planetary Axle.

Test Procedure

The test was performed as specified by John Deere Product Engineering. The only changes made to the Deere procedure were those necessary to compensate for a different spiral bevel gear ratio. This procedure is proprietary to Deere and Company.

Data Interpretation

The capacity for each engagement is the average torque during the middle of the engagement. The torque variation is the greatest difference between the maximum and minimum torque recorded during any 0.2-second portion of the engagement. The SwRI variation is the sum of all differences between the maximum torque and minimum torque for each engagement. It is obtained by summing all torque variations of each 0.2-second time block of all engagements.

Test Number

The run number listed on this report is a random number and is not sequential. Only SwRI® can link this run number to JDQ-96, LO271510, December 1, 2011.

John Deere JDQ-96 Performed using 1400 Series Axle

Results

Oil Code: LO271510	E.O.T. Date: December 1, 2011

The candidate results can be compared to the baseline reference average. Pass or fail decisions are only made by John Deere Product Engineering. The current reference baseline average is the average of the five most recent tests.

Current Reference Baseline Average (N · m)					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	330,753	340,749	339,241	341,212	1,351,955
Torque Variation	171,228	148,851	144,908	139,005	603,993

Results From Test Candidate LO271510					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	392,229	N/A	N/A	N/A	392,229
Torque Variation	264,603	N/A	N/A	N/A	264,603

Table 1 of the Appendix contains chatter test results from 1,000 cycles. Table 2 contains results of the five current baseline reference tests. Table 3 contains the history of tests conducted on reference oil and a graphic presentation of 1000-cycle reference results on LO271510.

Figures 1 and 2 are graphic presentations of candidate oil performance compared to baseline reference data.

Oil Code: LO271510	E.O.T. Date: December 1, 2011

Appendix

Tables

TABLE 1: JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES
Electrically Powered Test Stand

SwRI Oil Code LO-271510 Sponsor Oil Code LO271510

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	4548	2429	20	5010	1890	47	5021	1884	59	4914	1931	68
10	3831	4597	2484	21	4978	2213	47	4964	2215	58	4878	2240	68
15	3831	4679	3085	21	4981	2819	46	4976	2908	58	4888	2943	67
20	3831	4727	3692	21	4949	3679	47	4932	3797	58	4842	3854	67
25	3831	4738	4244	21	4919	4248	47	4887	4409	59	4819	4462	68
30	3831	4700	4171	22	4853	4830	48	4834	4915	59	4809	4918	68
35	3831	4645	3250	23	4748	4079	48	4772	5334	60	4808	5170	68
40	3831	4593	3081	24	4687	3026	48	4701	3010	60	4802	3101	68
45	3831	4534	2982	25	4683	3176	49	4714	3407	60	4808	3248	69
50	3831	4520	2916	27	4682	2930	49	4719	3259	61	4778	3135	69
55	3831	4471	2972	28	4680	3284	50	4704	3040	62	4742	3044	70
60	3831	4426	2926	30	4671	3236	51	4695	2947	63	4702	3110	71
15	1532	1793	2591	30	1860	2639	47	1918	2498	58	1888	2637	71
15	2300	2700	2778	30	2817	2947	45	2885	2635	58	2828	2919	64
15	3065	3659	3147	30	3834	3126	45	3892	2661	58	3801	3231	64
15	3831	4587	3329	30	4823	3393	46	4742	3085	58	4827	3521	64
15	4598	5586	3676	30	5754	3918	46	5463	3293	58	5794	3744	65
15	5364	6524	4234	30	6697	4163	46	6328	3495	58	6798	4170	65
15	6130	7416	3859	31	7161	3855	47	7029	3689	58	7235	4059	65
15	7050	7888	3332	31	8420	2543	47	8291	2731	58	8262	2786	65

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	95,330	65,176	1,067,069
49	99,208	65,992	1,057,131
60	98,467	65,211	1,079,366
71	99,223	68,224	1,088,670
TOTAL	392,229	264,603	4,292,236

TABLE 2: JDQ-96 Electric Initial Test Stand REFERENCE DATA

Candidate Oil Code : LO271510 EOT Date: December 1, 2011
Reference Oil Code : 69X31111M

	Cycles	Relative Capacity	Torque Variation	SwRI Variation	Average Facing Thickness (millimeters)
First Reference Run					
11279	1,000	329,975	160,449	2,530,213	7.45
	10,000	336,719	115,287	1,647,685	7.23
	20,000	334,984	119,314	1,755,276	7.03
	30,000	335,508	119,149	1,592,586	6.78
	Total	1,337,186	514,198	7,525,760	
Second Reference Run					
11852	1,000	327,258	172,283	2,624,608	7.42
	10,000	336,696	208,440	2,732,636	7.24
	20,000	339,033	152,391	2,143,494	7.08
	30,000	333,213	147,746	2,127,478	6.94
	Total	1,336,201	680,859	9,628,216	
Third Reference Run					
11663	1,000	325,464	179,529	2,696,409	7.43
	10,000	340,089	146,169	2,145,968	7.23
	20,000	330,568	145,948	2,016,724	7.07
	30,000	332,713	148,011	2,001,514	6.88
	Total	1,328,834	619,656	8,860,614	
Fourth Reference Rur					
11922	1,000	325,990	179,251	2,596,844	7.46
	10,000	334,464	156,902	2,185,176	7.31
	20,000	333,886	183,892	2,437,145	7.18
	30,000	339,695	147,072	2,033,787	7.07
	Total	1,334,036	667,118	9,252,951	
Fifth Reference Run					
11175	1,000	345,076	164,630	2,569,506	7.46
	10,000	355,779	117,458	1,636,195	7.26
	20,000	357,736	122,993	1,721,073	7.09
	30,000	364,928	133,050	1,799,847	6.84
	Total	1,423,519	538,132	7,726,620	
Candidate oil					
LO271510	1,000	392,229	264,603	4,292,236	

Table 3: History of 1000 cycle reference tests

Canidate Oil Code: LO271510 EOT Date: December 1, 2011

Oil Code	Comments	Torque Variation 1000 cycles
69X31111M	new piston and backing plate	160,449
69X31111M	new piston and backing plate	172,283
69X31111M	new piston and backing plate	179,529
69X31111M	new piston and backing plate	179,251
69X31111M	new piston and backing plate	164,630
69X31111M	new piston and backing plate	194,668
69X31111M	new piston and backing plate	183,301
LO271510	new piston and backing plate	264,603

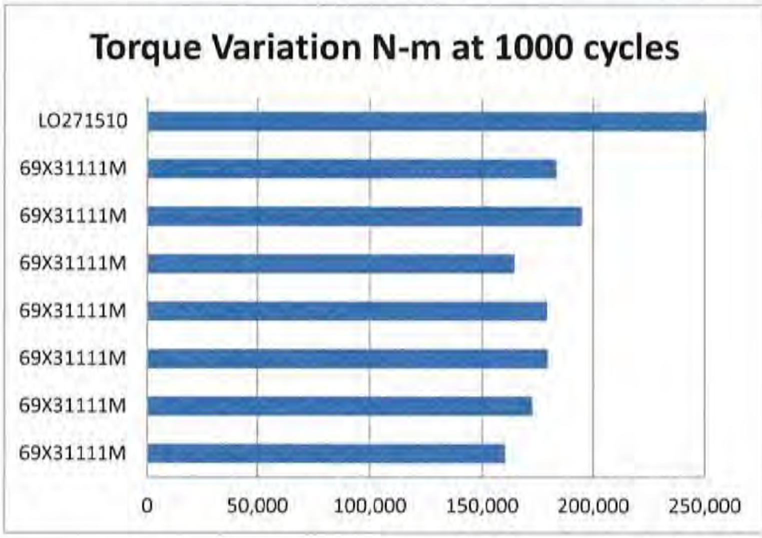


Figure 1

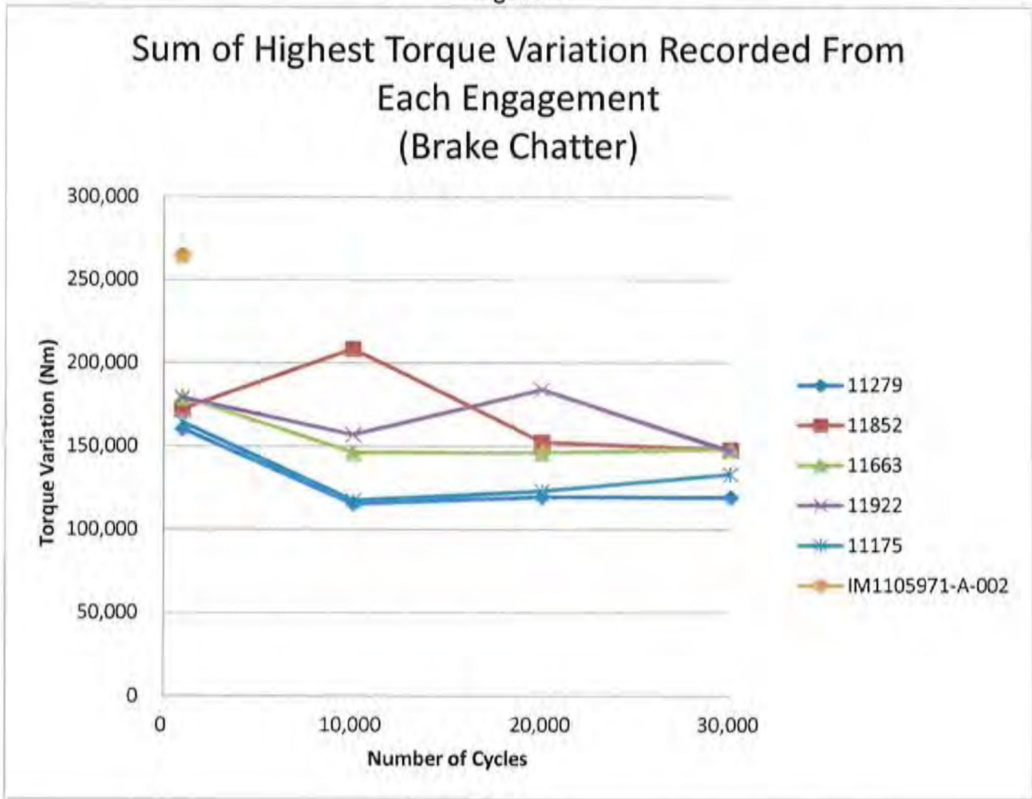
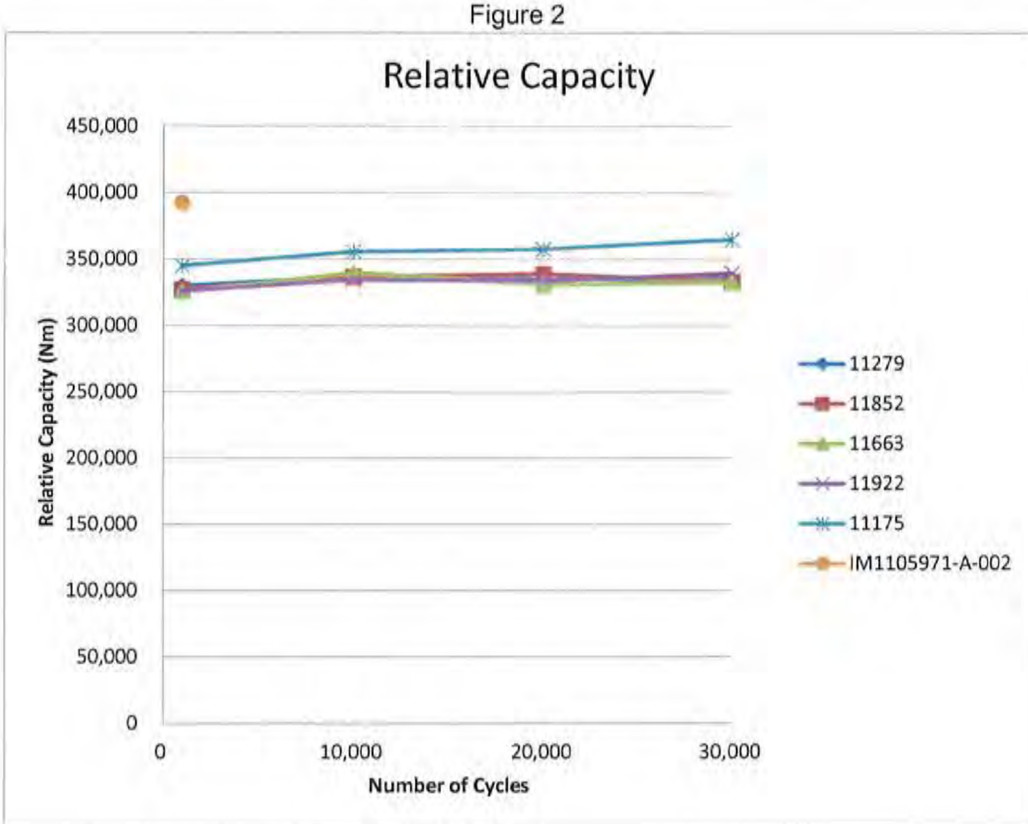


Figure 2



APPENDIX G
GEP 6.5L(T) TEST FUEL

Test Fuel Description:

Fuel used for engine durability testing was blended on site from commercially available Jet-A. To ensure that fuel lubricity impacts would have a minimized role on fuel system degradation resulting in reduced engine performance, a double max treat rate of lubricity additive DCI-4A was used during blending. The remaining two additives utilized in JP8, anti-icing and anti-static, were not used in the test fuel blend, as they have little to no impact on the fuel used in this application. Table G1 below shows the certificate of analysis (COA) for the Jet-A as purchased for blending. Table G2 shows the resulting fuel lubricity values after the double max treat rate of DCI-4A was successfully blended into the test fuel.

Table G1 – JET-A Certificate of Analysis

Alcor PetroLab, L.L.P.

20 Laboratory Road, Floresville, Texas 78114 Telephone 830-216-3113 www.alcorpetrolab.com

NuStar
San Antonio Products Terminal
P. O. Box 241017
San Antonio, Texas 78224-1017

February 22, 2010

Sample Type: Jet A
Tank Number.: 103
nt @ 1600 02/21/10 pu @ 0600 02/22/10

Sample Date: 02/22/10
Sample Time: 630

Volatility	Method	Specification		Result
Initial Boiling Point (°F)	D 86			320.0
Distillation 10% Rec (°F)		400	max	334.4
Distillation 50% Rec (°F)		Report		365.9
Distillation 90% Rec (°F)		Report		415.4
Distillation 95% Rec (°F)		Report		433.4
Distillation Final BP (°F)		572	max	459.5
Distillation Recovery (vol %)				98.9
Distillation Residue (vol %)		1.5	max	0.9
Distillation Loss (vol %)		1.5	max	0.2
Flash Point, Tag Closed (°F)	D 56	100	min	121.0
API Gravity @ 60 (°F)	D 1298	37.0 / 51.0		45.8
Cetane Index	D 4737	40.0	min	41.3
Particulate Matter Mgs/Gal	D 2276	3.0	max	0.8
Sulfur Wt %	D 7220	0.30	max	0.0001
Copper Strip	D130	No. 1	max	1A
Existent Gum Mgs / 100 Mls.	D381	7	max	<1.0
Fluidity				
Freezing Point (°F)	D 2386	-41.0	max	-76.9
Contaminants				
Color (Saybolt)	D 156	+15	min	+30
Appearance	D4176	clear/bright	pass/fail	Pass
Water Reaction: Change	D 1094	2.0	max	0
Water Reaction: Interface Rating	D 1094	2	max	1
Water Reaction: Separation Rating	D 1094	2	max	1
MSEP	D 3948	85	min	99

This Product Conforms to ASTM D1655 for the Above Tests: XX YES ____ NO

Reviewed and submitted by,

Chris Taylor CEO

Report Number: P022210A

Table G2 – JET-A Lubricity Test Results

Property	ASTM	Result
Scuffing Load BOCLE	D6078	3450
BOCLE	D5001	0.5
HFFR	D6079	0.69